AD-A084 362 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 8/8
LONG RANGE SPOIL DISPOSAL STUDY. PART I. GENERAL DATA FOR THE D--ETC(U)
1969 J CECALE, G STEINROCK

UNCLASSIFIED NL

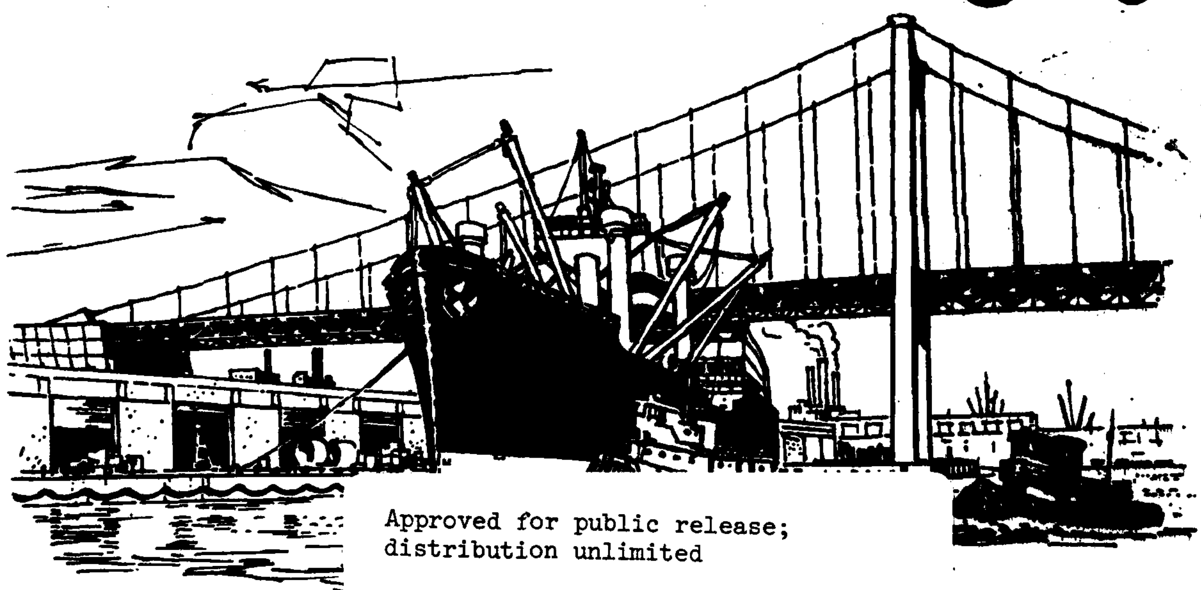
1 OF 1
AD A084362

END
DATE
FILMED
6-80
DTIC

LONG RANGE SPOIL DISPOSAL STUDY

PART I

GENERAL DATA FOR THE DELAWARE RIVER



U.S. ARMY ENGINEER DIST.
PHILADELPHIA
CORPS OF ENGINEERS
NORTH ATLANTIC DIVISION

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A084 362	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Long Range Spoil Disposal Study: Part 1, general data for Delaware River A070624		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Cecale, Mr. Joseph Steinrock, Mr. George		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Corps of Engineers Philadelphia District 2nd & Chestnut Sts. Phila. Pa. 19106		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS SAME		12. REPORT DATE 1969
		13. NUMBER OF PAGES 146
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) SAME		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Delaware River	Dredging	Wicker, C.F.
Navigation	Dredge Spoil disposal	
River channel	Philadelphia	
Shoaling	Delaware Estuary	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study of the Delaware River dredging spoil disposal problems was undertaken by the U.S. Army Corps of Engineers, Philadelphia District. Part I of this study focuses on the description of the Delaware River in regards to amount of water-borne commerce traveling over the river, problems associated with the port of Philadelphia and the necessary channel dimensions required for future water-borne transportation. A brief history of past dredging operations plus plans for private and federal development are described.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Appendix A of this document by C.F. Wicker focuses on the study of shoaling in the Delaware Estuary and its hydraulics including tidal data, salinity intrusion data and annual shoaling rates at several sediment stations.

LONG RANGE SPOIL DISPOSAL STUDY.

PART I.

GENERAL DATA FOR THE DELAWARE RIVER

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA
CORPS OF ENGINEERS
NORTH ATLANTIC DIVISION

TABLE OF CONTENTS

FOREWORD

The "Long Range Spoil Disposal Study" on the Delaware River was conceived in response to a request of the Chief of Engineers that an overall engineering study of the problems in the maintenance of the Delaware River be made with a view towards arriving at improved solutions.

Deep draft commerce moves 133 miles up the Delaware River. Over 100,000,000 tons of waterborne commerce is handled on this river each year. This commerce, in large part, relies on the man-made 40-ft. channel. Maintenance of this channel requires the removal of millions of yards of silt annually. The removal of this silt to a location on shore cannot proceed indefinitely because of diminishing disposal area availability. This study considers the possible course of future action.

The study is divided as follows:

PART I - GENERAL DATA ON THE DELAWARE RIVER furnishes the information and data on the Delaware River which is pertinent to the entire study.

PART II - SUB-STUDY 1, SHORT RANGE SOLUTION evaluates the remaining disposal area capacity in terms of its remaining life, and to recommend any further desirable and acceptable disposal area developments.

PART III - SUB-STUDY 2, NATURE, SOURCE, AND CAUSE OF THE SHOAL develops in depth the basic data as to the nature of the Delaware River shoals, their sources, and their causes. It is hoped that this knowledge may reveal new concepts for the better control of shoals.

PART IV - SUB-STUDY 3, DEVELOPMENT OF NEW DREDGING EQUIPMENT AND TECHNIQUE identifies the best in dredging plant and dredging technique for Delaware River dredging maintenance tasks now and in the future.

PART V - SUB-STUDY 4, PUMPING THROUGH LONG LINES examines the merits of transporting dredged materials many miles through pipelines.

PART VI - SUB-STUDY 5, IN-RIVER TRAINING WORK determines the potential of training works for control of shoaling. It involves considerable model testing.

PART VII - SUB-STUDY 6, DELAWARE RIVER ANCHORAGES considers the effect of man-made anchorage on shoaling problems and the merits of alternate solutions.

The complete Long Range Spoil Disposal Study is in seven parts. Part I, General Data on the Delaware River, will serve to give the general background information which is relevant to all parts of the overall study.

This part of the disposal study, exclusive of Appendix A, was prepared by Mr. Joseph Cecale, Project Engineer, Engineering Division, Philadelphia District, who was assisted by Mr. George Steinrock, also of the Engineering Division.

1 INTRODUCTION

The Delaware River flows nearly 135 miles from Trenton to the Sea (Plate 1). That distance alone emphasizes the importance of the Delaware River Navigation project. For, there can be no doubt that the navigation channel in the Delaware River has played a major role in the development of Philadelphia and the surrounding Delaware Valley into one of the most important centers of population and industry in the world.

However, this has not happened by accident. Although most generous to the Delaware Valley in many respects, nature did not endow the Delaware River with a channel adequate to accommodate modern ocean-going vessels. In its natural state, the Delaware River downstream of Philadelphia had a controlling depth of about 17 feet over a channel width which varied from 175 feet to 600 feet. Upstream, between Philadelphia and Trenton, the channel was narrow, crooked, and obstructed by shoals with depths of 3 to 8 feet. These were the conditions encountered by sailing vessels navigating the river in the early days. Needless to say, none ventured far upstream from Philadelphia. As the nation grew, increasing traffic on the Delaware and the growth of commerce in Philadelphia gave rise to demands for improvement of the river in the interest of navigation. As a result, the river has been under almost continuous improvement since 1836. It has been a constant struggle to keep improvement of the river abreast of the economic development of the area.

The earliest navigation improvements on the Delaware consisted of ice harbors and breakwaters to provide refuge for sailing vessels when ice was running or storms raging. Later improvements consisted of the removal of shoals at various locations. The first project for systematic improvement of the river was adopted by Congress in 1885. It provided for a channel 600 feet wide and 26 feet deep at low water from Philadelphia to deep water in Delaware Bay. That project was completed in 1898.

The growth of Philadelphia as a port and the transition from sails to steam began to be reflected in demands for a deeper channel even before the 26-ft. project was completed. In response, in 1899 Congress authorized deepening the channel to 30 feet from South Philadelphia to deep water in Delaware Bay, a distance of about 63 miles. The River and Harbor Act of 1910 authorized a channel 35 feet deep and 800 feet wide, with greater widths in Philadelphia Harbor and at bends. A 1930 modification provided anchorages at Port Richmond, Mantua Creek, Marcus Hook and Gloucester.

The existing project, pursuant to authorizations in the River and Harbor Acts of 1945 and 1954, provides for a channel 40 feet deep from Allegheny Avenue in Philadelphia to deep water in Delaware Bay, with widths ranging from 1,000 feet in the bay to 400 feet in Philadelphia Harbor. The project also provides for appropriate widening at critical bends and for an additional dredged area 37 feet deep and 400 to 600 feet in width in the Philadelphia Harbor. The project now includes six anchorages, located at Marcus Hook, Mantua Creek, Gloucester, Port Richmond, Deepwater Point and Reedy Point. There is a separate project for Delaware River from Philadelphia to Trenton, which provides for a channel 40 feet deep between Philadelphia and Newbold Island, a distance of 24 miles, and 35 feet deep on up to the Trenton Marine Terminal. The authorized Delaware River projects between Trenton and the Sea are shown on Plates 2 thru 4.

The 40-ft. channel, from the Philadelphia Navy Yard to the Sea, was constructed during World War II, principally as a national defense measure. In the post-war years the merchant fleet made increasing use of it and generated a phenomenal industrial growth in the Delaware

Valley. The rapid trend toward larger and more economic vessels soon began to emphasize the need for further deepening and widening of the channel. Local maritime interests once again petitioned Congress for help, and the Chief of Engineers was directed to make a study to determine the need for modification of channel dimensions and anchorage areas. That study is now being made under the direction of the District Engineer here in Philadelphia. Some local interests have requested that the channel be deepened to 50 feet and extended to widths varying from 1,000 feet to 2,000 feet, as indicated by conditions on each range. The petroleum interests desire a 72-ft. deep channel from the Atlantic Ocean into the location of a projected deep water unloading terminal in Delaware Bay.

II RELATIONSHIP OF THE DELAWARE RIVER CHANNEL TO THE DELAWARE VALLEY

The total drainage areas at the mouth and Trenton, New Jersey, which represents the head of tide, are respectively 12,765 and 6,870 square miles, and the mean daily fresh water discharge at Trenton, based on 53 years of stream flow record, is 11,500 c.f.s. The major tributaries draining into the Delaware in the 130 mile long tidal portion include the *Neshaminy Creek, 233 square miles;* Rancocas Creek, 342 square miles; Schuylkill River, 1910 square miles; Christina River, 568 square miles; and Maurice River, 388 square miles.

The Delaware River is connected to both the Raritan River in northern New Jersey by the Delaware and Raritan Canals and to the Chesapeake Bay by the Chesapeake and Delaware Canal. The former canal is used primarily to supply water for municipal and industrial purposes, and the latter is used for navigation and has an authorized channel 35 feet deep and 450 feet wide. The Chesapeake and Delaware Canal provides an inland water course from Baltimore to Philadelphia and reduces the travel distance from Baltimore to both Philadelphia and New York by respectively 285 and 150 miles. The tidal portion of the Delaware River is subject to semidiurnal tidal action from the Atlantic Ocean and has a mean tidal range increasing from 4.0 feet at the mouth to 6.9 feet at Trenton. The normal tidal current in the channel has a velocity of less than 3 knots. Salt water intrusion does not normally extend beyond Claymont, Delaware, which is approximately 25 miles south of Philadelphia.

The above portion of the Delaware River flows through 11 counties in three states, including New Castle in Delaware, Chester, Delaware, Montgomery, Philadelphia, and Bucks in Pennsylvania, and Salem, Gloucester, Camden, Burlington, and Mercer in New Jersey. Many important harbors such as Philadelphia, Trenton, Camden, Marcus Hook, Chester, Wilmington, and Paulsboro are situated along its banks. The combined population of the above area was 4,975,446 in 1960 and is expected to reach 7,000,000 by 1990. It is further estimated that 60,000,000 people live within a 400-mile radius of the port area, serving as an illustration of the tremendous consumer market area of the Delaware Valley.

The ports of the Delaware River, as a whole, lead the United States in total international commerce traffic, and rate second nationally and third internationally in total water-borne commerce. Although over 9,000 manufacturing plants, representing 90 percent of all the industrial types classified by the United States Bureau of Census, are located in this area, the oil and steel industries are the largest, with both these industries dependent upon deep-draft navigation. Over 100,000 jobs in the Delaware Valley are directly dependent upon port activity which directly and indirectly generates a total income of over two billion dollars each year. These figures give evidence to the fact that the commerce of the Delaware River contributes substantially to the economy of the Delaware Valley, a section which has been one of the most rapidly developing areas in the United States.

III AMOUNT OF WATER-BORNE COMMERCE

The amount of water-borne commerce between Trenton and the Sea has increased from 88,600,000 tons in 1955 to 113,500,000 tons in 1966. A total of 211,380 water-borne trips were made during 1966 from Trenton to the Sea, including 27,580 classified as foreign and coastwise trips and 183,800 as internal trips. These classifications are defined in the "Water-borne Commerce of the United States" as follows:

Foreign: Traffic between the United States and foreign ports, including the Canal Zone.

Coastwise: Traffic between ports of the United States requiring carriage over oceans or the Gulf of Mexico.

Internal: Traffic between ports wherein the entire trip is made through inland waterways.

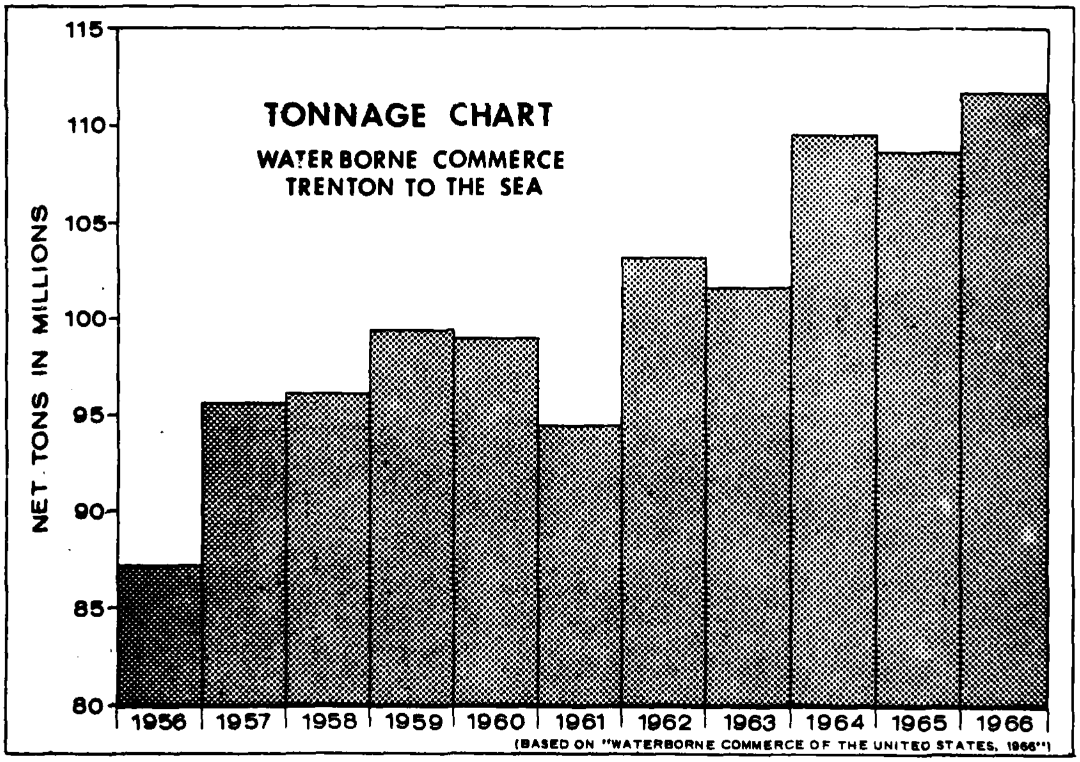


Table 1

TABLE 1
WATERBORNE TRAFFIC CALENDAR YEAR 1966-TRIPS

	Passenger & Dry Cargo		Tanker		Tow Boat or Tug Boat		
	Foreign & Coastal	Internal	Foreign & Coastal	Internal	Foreign & Coastal	Internal	Totals
Trenton to the Sea							
Upbound							
Self-propelled	10,619	51,834	2,335	720	468	22,492	
Non-self propelled	63	9,375	259	6,333	–	–	
Total - Upbound							104,498
Downbound							
Self-propelled	10,640	52,404	2,363	762	498	22,882	
Non-self propelled	55	9,756	279	6,255	–	–	
Total - Downbound							105,894
Total - Trenton to the Sea							210,392
Philadelphia to the Sea							
Inbound							
Self-propelled	16,686		2,174		10,852		
Non-self propelled	2,714		3,528		–		
Total - Inbound							35,954
Outbound							
Self-propelled	16,573		2,268		10,241		
Non-self propelled	2,673		3,755		–		
Total - Outbound							35,510
Total - Philadelphia to the Sea							71,464

A breakdown of water-borne commerce mentioned above, together with the traffic totals from Philadelphia to the Sea, is shown in Table 1.

A total of 200,000 vessels, including all the tow and tugboats and virtually all the non-self propelled vessels, were recorded as having drafts of 18 feet or less. On the other hand, 115 vessels were reported to have drafts of 40 feet or greater. These included five tankers with 45 - 46 ft. drafts and 110 vessels, of which 26 were dry cargo or passenger vessels, and 84 tankers with 40 - 41 ft. drafts.

The principal cargoes include anthracite and bituminous coal, lignite, gasoline, gas, oil, residual fuel oil, crude petroleum, lubricating oil and grease, other petroleum products, sugar, sulphuric acid, iron, ore, sand, gravel and crushed rock.

IV PROBLEMS ASSOCIATED WITH INLAND LOCATION OF PORT OF PHILADELPHIA

The relatively long distance between Trenton and Philadelphia to the Sea, 135 and 100 miles respectively, results in both high initial costs for channel improvements and its maintenance. At the present time approximately 7,000,000 c.y. of shoal material is removed annually from the Delaware River between Philadelphia and the Sea at a cost of over $3,000,000. Associated with the improvements and maintenance is that of providing adequate disposal sites for the dredged spoil. The once vast tidal marsh areas along the estuary are rapidly disappearing. In addition, there are strong objections from fish and wildlife interests to the use of these remaining areas for spoil disposal sites and increasing opposition to the acquisition of marginal farm lands for this purpose.

The long distance from Philadelphia and the Sea also requires construction of anchorages at regular intervals to serve as refuges for vessels during periods when hazardous navigation conditions prevail and when docking facilities are not available. These anchorages which vary in length between 7,000 feet and 18,000 feet, with widths of 2,300 feet further aggrevate the disposal problem. The recently authorized enlargement of the Mantua Creek and Marcus Hook anchorages and construction of a new anchorage at Deepwater Point and Reedy Point will require the initial removal of approximately 40,000,000 c.y. The additional annual maintenance of the four anchorages is estimated at 800,000 c.y. Another problem associated with the navigation channel is the effect on marine life by turbidity due to dredging operations. There are also problems of bank erosion attributed to wave wash from passing vessels. Disposal areas along the shore are usually reveted within the tidal zone to eliminate erosion of the retaining dikes.

Each enlargement of the channel requires detailed studies to determine the effect on ground water supplies in southern New Jersey or Delaware. Detailed studies are also made regarding salt water intrusion and the effect the change in salinity and turbidity may have on marine life.

The physical and hydraulic characteristics of the Delaware estuary are presented in the Appendix to this report.

V AUTHORIZATIONS FOR NAVIGATIONAL DEVELOPMENT OF THE DELAWARE RIVER AND ITS TRIBUTARIES

There are three navigation projects presently authorized on the Delaware River between Trenton and the Sea. These are the Delaware River, Philadelphia, Pa. to Trenton, N.J. (adopted in 1930 and modified in 1935, 37, 46 and 54); Philadelphia to the Sea (adopted in 1910 and modified in 1930, 33, 35, 38, 45, 54 and 58); and Delaware River at Camden, N.J. (adopted in 1919 and modified in 1930 and 1945). The existing authorized projects together with the modifications thereto are shown on Tables II and III. The current authorized channel sizes are:

Reach	Depth (feet)	Width (feet)
P.R.R. Br. (Trenton, N.J.) -Trenton Marine Terminal	12	200
Trenton Marine Terminal - Newbold Island	35	300
Newbold Island - Allegheny Ave., Philadelphia, Pa.	40	400
Allegheny Ave., Phila. - W. Horseshoe Range (west side)	40	400-500
Allegheny Ave., Phila. - W. Horseshoe Range (east side)	37	500-600
W. Horseshoe Range - Bombay Hook Pt.	40	800
Bombay Hook Pt. - Cape Henelopen	40	1,000

In addition, the following features are authorized:

(1) Suitable widening at bends.

(2) A 35-ft. deep, 800-ft. wide, 1700-ft. long turning basin at the Trenton Marine Terminal.

(3) A 20-ft. deep, 200-ft. wide auxiliary channel east of Burlington Island with a 20-ft. deep, 450-ft. wide turning basin at the upper end.

(4) An 8-ft. deep, 200-ft. wide cross channel opposite Delanco, N.J.

(5) Relocation of the channel at the Delair R.R. Bridge and reconstruction of the bridge.

(6) A channel at Camden, N.J. from Cooper Point to Newton Creek between the 37-ft. channel and a line 50 feet west of the eastern pierhead line with depths of 18, 37 and 30 feet.

(7) Construction of six anchorages.

(8) Construction of dikes and training works for regulation and control of tidal flow.

The following portions of the above work have not been completed and are presently deferred for future studies.

(1) Dredging the portion between Newbold Island and Trenton to a depth of 35 feet, including the turning basin at Trenton Marine Terminal. This work has been deferred pending required improvements to port facilities by local interests.

(2) Dredging the channel at Camden from 30 to 37 feet in depth, except that portion in front of the Camden Marine Terminal.

(3) Dredging the east side of the channel in Philadelphia Harbor from 35 feet to 37 feet in depth and deepening Port Richmond Anchorage to 37 feet deep.

Other work not yet completed, but not deferred, includes completion of Mantua

TABLE II

AUTHORIZED PROJECTS IN THE DELAWARE RIVER

TRENTON TO THE SEA

PHILADELPHIA TO THE SEA

Acts	Work Authorized	Documents
June 25, 1910	Channel 35 feet from Allegheny Avenue, Phila., Pa. to Delaware Bay	H. Doc. 733, 61st Cong., 2d Sess.
July 3, 1930	Anchorages 35 feet deep at Port Richmond and Mantua Creek, a 30-ft. anchorage at Gloucester, N.J. and extending 1,000-ft. channel in Philadelphia Harbor to Horseshoe Bend	H. Doc. 304, 71st Cong., 2d Sess.[1]
Aug. 30, 1935[2]	An anchorage 35 feet deep at Marcus Hook, Pa.	Rivers and Harbors Committee Doc. 5, 73d Cong., 1st Sess.
June 20, 1938[3]	A channel 37 feet deep from Philadelphia-Camden Bridge to Navy Yard, thence 40 feet deep to deepwater in Delaware Bay	S. Doc. 159, 75th Cong., 3d Sess.[1]
Mar. 2, 1945[4]	A 37-ft. depth in channel from Allegheny Ave., Phila., Pa. to Philadelphia-Camden Bridge and to anchorage to Port Richmond.	H. Doc. 580, 76th Cong., 3d Sess.[1]
Do...	A 37-ft. depth in and enlargement of anchorages near Mantua Creek and Marcus Hook	H. Doc. 340, 77th Cong., 1st Sess.[1]
Do...	Maintenance of enlarged channel opposite Philadelphia Navy Yard	Specified in Act.
Sep. 3, 1954	A channel from Allegheny Ave. to Naval Base 40 feet deep, 400 feet wide along west side of channel through Phila. Harbor and 500 feet wide through Horseshoe Bend	H. Doc. 358, 83d Cong., 2d Sess.[1]
July 3, 1958	Anchorages at Reedy Point, Deepwater Point, Marcus Hook, and Mantua Creek. 40 feet deep and 2,300 feet wide with mean lengths of 8,000, 5,200, 13,650 and 11,500 feet, respectively	H. Doc. 185, 85th Cong., 1st Sess.

1. Contains latest published maps.
2. Also Public Works Administration, September 6, 1933.
3. Channel 37 feet deep and 600 feet wide from Naval Base to Philadelphia-Camden Bridge, deferred for restudy.
4. Channel 37 feet deep and 600 feet wide from Philadelphia-Camden Bridge to Allegheny Avenue, deferred for restudy.

TABLE III
AUTHORIZED PROJECTS IN THE DELAWARE RIVER
TRENTON TO THE SEA

PHILADELPHIA TO TRENTON

Acts	Work Authorized	Documents
July 3, 1930	A channel 28 feet deep, 300 ft. wide between Allegheny Ave., Phila., Pa. and Delair Bridge	Rivers and Harbors Committee Doc. 3, 71st Cong., 1st Sess.
Aug. 30, 1935[1]	Channel 25 feet deep from Delair Bridge to Trenton, N.J. and maintenance of 12-ft. channel from upper end of 25-ft. project to Penna. R.R. Bridge at Ferry St., Trenton	Rivers and Harbors Committee Doc. 11, 73d Cong., 1st Sess.
Aug. 30, 1935[1]	Auxiliary channel, 20 feet deep, east of Burlington Island	Rivers and Harbors Committee Doc. 66, 74th Cong., 1st Sess.[2]
Aug. 26, 1937	A cross channel 8 feet, opposite Delanco, N.J.	Rivers and Harbors Committee Doc. 90, 74th Cong., 2d Sess.
July 24, 1946	Anchorage at mouth of Biles Creek	House Document 679, 79th Cong., 2d Sess.
Sept. 3, 1954	A channel 40 feet deep and 400 feet wide between Allegheny Ave., Phila., Pa. and upstream end of Newbold Island, thence 35-ft. deep to Trenton Marine Terminal, and turning basin to 800-ft. wide. Relocation of channel at railroad bridge at Delair and suitable reconstruction of bridge. Construct necessary bank protection works; and eliminate authorized anchorage near mouth of Biles Creek, Pa.	House Document 358, 83d Cong., 2d Sess.[2]

1. Also Public Works Administration, September 6, 1933, and Emergency Relief Administration, May 28, 1936.
2. Contains latest published maps.

Table III

TABLE IV DELAWARE RIVER TRIBUTARIES

Tributary	GENERAL		CHANNEL FEATURES			STATUS		
	Adopt	Modif.	Authorized Channel (Feet)	No. of Reaches	Total Length (Miles)	New Work Completed	Work Remaining	Maintenance Efforts
Schuylkill R	1917	1930,46	22-33x200-400	4	6.0	FY 62		FY 68
Chester R	1919		8x50-60	2	0.2	Inactive		Inactive
Christina R	1896	1922,30,35, 40,60	7-35x100-400	5	9.9	FY 62		FY 67
(C & D Canal	1935	1954	35x450	1	46.0	60%		NA
(Branch Canal	1935		8x50	1	2.0	Inactive		Inactive
Appoquinimink R	1890		8x100	1	6.75	To 7.0'	To 80'	Inactive
Smyrna R	1910		7x60-100	1	9.5	1939		FY 48-49
Leipsig R	1910	1912	5-6x40-50	2	14.0	1914		Inactive
Little R	1912		5x40-60	2	3.0	1914		FY 66
St. Jones R	1910,12	1937,60	7x50-60	2	6.5	1933	Jetties & Entr. Channel	FY 37
Murderkill R	1892		7x60-150	2	9.5	1911	7x150 entr ch	FY 64
Mispillion R	1919	1937,54	9x60-80	2	13.4	1939	Dredge to 9', 3 cutoffs & Turning Basin	FY 64
Broadkill R	1873	1907,53[1]	6x40	1	10.25	1913		FY 66
Rancocas R	1881		5-6x150-200	2	13.0	1903	Mt. Holly Branch	FY 42
Cooper R	1896		12x70	1	1.75	1920		FY 62
Big Timber Cr	1930	1935	10x60-75	2	5.5	1941		FY 62
Woodbury Cr	1913		6x40-60	2	3.75	1916		FY 44
Mantua Cr	1899, 1907	1935,38	7-20x60-110	4	7.0	1940		FY 63-65
Raccoon Cr	1902	1907, 19	7x40-75	3	9.75	1922		FY 65
Oldsman Cr	1910		5-6x40-100	3	10.0	1915	Constr of Jetty	Inactive
Salem R	1925		12x100-150	2	5.0	1928	Dredge Channel in L. Salem	FY 61
Alloway Cr	1890	1896, 1907	6x60-75	2	9.5	1909		Inactive
Cohansey R	1907	1937	8-12x75-100	3	19.5	1939		FY 66
Maurice R	1910	1935	7-8x60-150	3	24.0	1933	Deepen portion of entr channel to proj. depth	FY 41
Dennis Cr	1896		8x60	1	5.5	1897		Inactive
Goshen Cr	1891	1899	3x30-50	2	2.0	1900		Inactive

1. 1953 modification deleted entrance channel from Delaware Bay. Entrance is now from Lewis & Rehoboth Canal

Table IV

Creek Anchorage and constructing Reedy Point and Deepwater Point Anchorages.

The total amount expended on the above project as of 30 June 1966 is $129,709,000, with the following cost for each project:

Philadelphia to Trenton	$ 72,162,800
Philadelphia to the Sea	57,068,300
Delaware River at Camden	477,900
Total	$129,709,000

In addition to the three authorized projects on the Delaware River, there are 24 tributaries having authorized projects. A description of the projects, status and latest maintenance effort is presented in Table IV. The locations of the tributaries are shown on Plate 1. The two major tributaries, Schuylkill River and Christina River (Wilmington Harbor) are shown on Plates 5 and 6.

VI CHANNEL DIMENSIONS FOR SAFE NAVIGATION

The authorized channel for the Delaware River accommodates today's vessels safely and efficiently. Bulletin No. 38 of the Permanent International Association of Navigation Congresses, July 1953, with respect to "Depths to be Created in Seaports, Entrance Channels and Berths", contains pertinent data for consideration in determining the economically optimum depth of the channel of the Delaware River. The report states that channel depths are generally based on drafts of vessels using the channel, plus allowances for sufficient water under the keel, squat, trim, moving from salt to fresh water, and low tides. As referred to in the report, the ideal objective in establishing channel dimensions is to afford a safe and efficient waterway for the size and number of vessels expected to use the facility within the reasonably foreseeable future; the basic objective to be limited, of course, to sound economic justification, but the channel dimensions to be adequate to permit the largest commercial vessels in frequent use or proposed for frequent use, to operate without undue hazard or delay under conditions of weather, vessel traffic, tidal phenomenon, or other conditions affecting navigation. Data as to the allowances for drafts of vessels recommended in the report for channel depths, considered applicable to the channel of the Delaware River, are as follows:

a. SUFFICIENT WATER UNDER THE KEEL: This varies somewhat according to the size and speed of the ship, but an additional 2 feet has generally been considered to be the minimum for this purpose.

b. SQUAT: Studies, conducted in 1936, of vessels using the Delaware River have indicated that the average ship moving at 12 knots will squat 2.5 feet, and for some types the squat is as much as 3.5 feet. Because of the long distance from the sea to the main port facilities, it has been considered that vessels should be able to operate at speeds comparable with those at sea, except when passing other vessels moored at piers and wharves where damage from excessive wave action may occur. It is considered reasonable to assume a squat of 3 feet for the average ship using the Delaware River toward determining the appropriate depth of the channel.

c. TRIM: The larger vessels are designed to float on an even keel, forward and aft, when in loaded condition. In actual operations, however, vessels are usually trimmed with a drag of 1 to 2 feet to prevent them from becoming bow-heavy. It is believed that no special consideration need be given to the trim of the vessels using the Delaware River since the amount of trim would generally be included in the overall drafts of the vessels.

d. MOVING FROM SALT TO FRESH WATER: The loss in buoyancy in moving from salt water to fresh water is a factor for consideration for ships travelling to Philadelphia. A ship drawing 30 feet at sea would draw 30 feet, 8 inches at Philadelphia. An allowance of one foot for travelling from salt to fresh water is considered to be reasonable.

e. LOW TIDES: It has been determined from tidal observations of the Delaware River at Reedy Point, Delaware, that the low tide falls 2 feet or more below the plane of mean low water an average of five times a year and 1 foot or more below the plane of mean low water an average of 34 times a year. The extreme low tides occur in the Delaware River when strong northwest winds prevail for periods of from two to three days. The larger ships do take advantage, however, of the higher stages of tide in transiting the Delaware River, and the extreme low tides of the waterway, because of their relative infrequency, are not considered to be an essential factor in determining the depth of the channel.

Allowing only 2 feet for sufficient water under the keel, 3 feet for squat, and 1 foot for moving from salt to fresh water, the sum is 6 feet. This is the same as the tidal range at Philadelphia and 2 feet greater than the tidal range at Delaware Breakwater at the Capes. Inbound vessels drawing 34 feet or more do not normally attempt to transit the Delaware River except on a rising tide which can be followed upstream to Philadelphia. The drafts of the vessels travelling to Philadelphia have generally been limited to 36 feet. It is obvious that with the present depth of the channel, vessels of 36-ft. draft must take advantage of full high water stage and that vessels with greater draft cannot safely, or efficiently, use the existing channel.

VII WIDTH REQUIRED FOR SAFE NAVIGATION

It has been determined from the data and findings of studies presented in the Report of the Governor of the Panama Canal, published under Public Law 280, 79th Congress, 1st Session, that for the safe two-way operation of vessels in a canal, the channel width should provide between the meeting vessels a clearance lane having a width equal to the width of the larger ship, a maneuvering lane for each vessel having width 180 percent of the width of the ship, and a clearance lane between each vessel and the canal bank having a width equal to the width of the ship. It is considered that in the case of the Delaware River, where the banks are at greater distances from the channel than those in a constricted canal and where normal side slopes prevail on each side of the channel, the clearance lane between the vessel and the bank is not a factor. The largest vessels regularly using the Delaware River to Morrisville, Pennsylvania, about 25 miles above Philadelphia, are ore carriers with lengths up to 736 feet and beams up to 98 feet. The largest tanker to have travelled to Philadelphia has a length of 855 feet and beam of 125 feet. By using the criteria in the Report of the Governor of the Panama Canal considered applicable to the passage of such vessels in Delaware Bay and River, the channel from the Sea to Philadelphia should have a bottom width of 825 feet and the channel from Philadelphia to Trenton should have a bottom width of about 650 feet. The authorized 800-ft. wide channel from the Sea to Philadelphia, widened at bends to accommodate the turns of larger vessels, substantially meets the criteria. The greater part of this channel is in open and exposed water, however, and is often subjected to strong winds, inducing cross currents, and adverse weather conditions such as fog and snow. A wider channel than presently authorized would provide vessels a safer degree of navigation. The use of bridge-to-bridge radio communication, which is a system in being, between the larger vessels and with extreme prudence and caution being exercised by the agents and navigators of the vessels, the channel width is accommodating navigation. It is important, of course, that the full channel width be maintained in order to provide for at least the minimum safety for navigation.

VIII DEVELOPMENT OF NAVIGATION IMPROVEMENTS FROM INITIAL CONCEPT TO PRESENT DAY

In addition to the projects mentioned in the preceding section, various other navigational improvements have been provided. One of the earliest improvements was the construction of breakwaters to provide safe havens from ice and storms, the most notable of which was the Harbor of Refuge at Cape Henelopen. This structure, which was built between 1828 and 1869 at a cost of $2,000,000, consisted of 2,558 feet of stone breakwater and had a top elevation of 12 to 14 feet above MLW. A later project providing an 8,000-ft. long breakwater, 15 ice piers, and a channel including a turning basin was authorized in 1896, modified in 1930 and 1935, and completed in 1951.

Other similar projects included the ice harbors at Marcus Hook and New Castle. The former was adopted in 1867, modified in 1880, 1881 and 1888, and completed in 1889. It provided for construction of seven ice piers, a bulkhead, repair to existing wharves and piers, and dredging to depths of 12 to 24 feet. The latter project was adopted in 1884 and completed in 1889, and consisted of constructing a new ice pier and repairing others. Both of these projects are presently classified as inactive.

As part of the original authorization for Philadelphia to the Sea in 1910, provisions were made for the construction of dikes for the purpose of regulating tidal flow. In keeping with this, four dikes classified as the Delaware River dikes have been constructed south of Philadelphia. These are the Hope Creek, Reedy Island, Pea Patch Island, and Pennsville Dikes, located respectively 21, 16, 4 and 1 miles downstream of the Delaware Memorial Bridge and are shown on Figure 3.

The construction of Hope Creek Dike comprised the first phase of the construction of these spur dikes, extending perpendicularly from the Jersey shore line. The purpose of these dikes was to constrict the river in the reach where maximum shoaling had been experienced and cause flood and ebb currents to flow parallel to the channel. The Hope Creek Dike consists of a two-row timber pile dike having a top elevation of +2 MLW and a length of 3,422 feet was completed in 1929 at a cost of $135,400. In addition, a concrete light base was constructed to elevation +10 MLW at the riverward end of the dike and a stone mound placed around the outer end of the dike and the light base. The concrete superstructure, except for the outer 505 feet, which was completed in 1930 by Government plant and hired labor forces, was completed in 1931 by contract. Repairs were made in 1934 as a result of the 1933 storm and again in 1936. As a result of a visual inspection made in 1961, the dike was found to be in relatively good condition with no appreciable settlement apparent.

A 6,300-ft. long portion of the existing Reedy Island Dike was originally constructed between 1887 and 1889. The dike, which was founded on a soft clay layer extending to a depth of over 60 feet, consisted of brush mattress and stone and its top elevation was at +5 feet MLW. An examination in 1895 indicated settlement of from 2.5 to 4.0 feet. As a result, a project was initiated in January 1896 to raise the top to +8 feet MLW and to extend the dike southward to the Delaware shore line, a distance of 11,600 feet. Operations were halted in June 1896 so that a review could be made. The result of this review was to discontinue dike construction. Because of continued shoaling in the channel, perimeter dikes for Artificial Island, located on the Jersey side of the channel opposite the Reedy Island Dike, were constructed to elevation +10 MLW between 1900 and 1905 for the purpose of providing a disposal area for material dredged from the channel. In 1912, the raising and extension of Reedy Island Dike was continued and eventually completed in 1919. The original alignment, however, had been revised to parallel the Delaware shore line and navigation channel. When completed, the dike was 16,900 feet in length, of which 11,200 feet had a top elevation of +8 MLW, and the remaining portions a top elevation at or below MLW. The present condition of the dike is that considerable settlement has taken place and several sections have been breached. However, the dike continues to perform its function of keeping the Baker and Reedy Island ranges practically free of shoaling.

Pea Patch Island Dike is situated adjacent to the downstream end of Deepwater Point range and the upstream end of New Castle range. This area experienced particularly heavy shoaling prior to 1930, the cause for this shoaling being the lack of parallelism between the main currents and the dredged channel. During flood flows the currents swung around Pennsylvania side of Pea Patch Island, while the ebb tide deflected from the New Jersey shore line below Deepwater Point. The dike, which is nearly 20,000 feet long, with a top elevation of from 2.5 to 10.0 feet above MLW, was constructed in four sections between 1930 and 1932, each of which varied as to type of construction. The types of construction are steel sheet pile, timber crib filled with stone, both with concrete test caps (placed during 1932 and 1933) and without caps, and steel sheet pile cell sections. Three navigation lights were constructed as part of the original structure, with two additional being installed in 1949-50. The dike was last repaired in 1953, the repair consisting of raising settled portions of the dike. In 1963 an investigation which utilized the services of a diver revealed that considerable settlement and deterioration had occurred, particularly to the steel sheet pile fencing. Several plans with comparative estimates showed that the cost for the rehabilitation would exceed $4,000,000. In view of the high cost, model tests were undertaken in 1963 at the U.S. Army Waterways Experiment Station in Vicksburg, Mississippi, to determine the need for and extent of required rehabilitation. The results showed that the damaged sections have little influence on shoaling characteristics of the adjacent channel.

Following the construction of Pea Patch Island Dike, the shoaling rate in Deepwater Point range decreased for several years, after which it reappeared at a slightly upstream location. In an effort to reduce the shoaling, Pennsville Dike was constructed between 1942 and 1943 at a cost of $1,000,000. The dike consists of a 2,300-ft. long leg of rock fill, extending at an angle of 45° from the New Jersey shore line, and a 2,900-ft. long leg constructed of timber cribbing filled with brush and stone parallel to the channel alignment. Investigations in 1962 showed the dike to be in a deteriorated condition. Model tests were undertaken in 1963 by the Waterways Experiment Station and the results showed that for the dike to be functional it should be raised to mid-tide (elev. +3). The corrective work was accomplished in 1963 and included repair of timber crib sections, replacement of missing wooden piles, and raising of the structure to elevation +3 MLW. The cost of the rehabilitation was $340,575.

Numerous other dikes have been constructed for the purpose of reducing shoaling and improving navigation. The dikes fall into two general classifications, namely, training dikes and contraction dikes. Training dikes are constructed parallel to the channel and serve to direct currents in the river. Contraction dikes are formed either by tying one or both ends of a longitudinal dike to the shore or by closing off one end of a channel formed by an island in the river. In both cases the dike constricts the flow of the river, causing higher velocities and straighter direction of flow. The initial phase of Reedy Island Dike, described above, is an example of a training dike, while the dikes constructed at Bulkhead Bar in 1891-92 and those at Chester Island, Oldmans Point and Stoney Point - Artificial Island in 1912-15 illustrate contraction dikes. Still others, such as the Fishers Point and Hog Island-Mifflin Island dikes may be regarded as a combination of the above types. The Fishers Point Dike extends longitudinally southward from the New Jersey shore line toward Pettys Island, closing off a portion of the east channel. The dike which originally was constructed in 1885-86 was intended to reduce the shoaling that resulted in the formation of a bar extending diagonally from Five Mile Point on the Pennsylvania shore to the upstream end of Pettys Island. The latter dike which extended from Hog Island to Tinicum Island was constructed in 1885-1888 to reduce shoaling in Fort Mifflin Bar. This bar extended diagonally from the head of Tinicum Island to the mouth of Woodbury Creek. In 1898, two islands situated in midstream between Philadelphia and Camden were removed. These islands, Smith and Windmill, had long been regarded as a hindrance to navigation in this area.

Pursuant to the provisions of Section 1 of the Act of 22 April 1940 (54 Stat. 150; 33 U.S.C. 180), and Section 7 of the River and Harbor Act of 4 March 1915 (38 Stat. 1053; 33 U.S.C. 471), a total of 17 areas have been designated as special anchorages or anchorage grounds. Six of these were later authorized for improvement and are described in Table II. The anchorage grounds are described below and are shown in "Anchorage Regulations, Delaware Bay and River", published by the U.S. Army Corps of Engineers.

Anchorage No.	Designation	Range	Remarks	Length	Width
1	Bombay Hook Point	Liston	W side of Channel near Ship Light	23,700	4,800
2	Artificial Island	Reedy Island	E side of Channel used for Explosives	13,400	2,400
3	Reedy Point-SE	Reedy Island	Authorized Anchorage	8,000	2,300
4	Reedy Point-N	New Castle	(W side of back (Channel, north of (C & D Canal	4,500	1,100
5	Pea Patch Island	New Castle	E side of Channel vic Pea Patch Island	7,000	1,600

Continued

Anchorage No.	Designation	Range	Remarks	Length	Width
6	Deepwater Point	Cherry Island	Authorized Anchorage	5,200	2,300
7	Marcus Hook	Marcus Hook	Authorized Anchorage	13,650	2,300
8	Thompson Point	Tinicum Island	E side of Channel betw Crab Pt & Monds Island	3,400	700-1300
9	Mantua Creek	Mifflin Bar	Authorized Anchorage	11,500	2,300
10	Naval Base	W Horseshoe	W side of Channel (League Island)	2,600	12-1500
11	Gloucester	E Horseshoe	Authorized Anchorage	3,500	400
12	Gloucester- Camden	Phila Harbor	E side of Channel vic Kaighn, Greenwich Pt	10,500	700
13	Camden	Phila Harbor	E side of Channel vic Cooper Pt	2,200	800
14	Port Richmond	Phila Harbor	Authorized Anchorage	6,400	750
15	Petty Island	Phila Harbor	E side of Channel N end of Island	2,200	800
16	5-Mile Point	Harbor-Draw	W side of Channel opp Fishers Pt	6.500	700

IX HISTORY OF DREDGING OPERATIONS

The bulk of the new and maintenance material removed from the Delaware River channel between Philadelphia and the Sea has been accomplished by use of Government-owned hopper dredges. Hopper dredges are usually the most economical primarily because the dredged material must usually be hauled several miles to a disposal site. Work in the project channel between Philadelphia and Trenton, New Jersey, is performed by contract with pipeline dredges. Disposal areas for this portion of the waterway are furnished by the State of New Jersey and the Commonwealth of Pennsylvania. Contract dredging is also used for both new and maintenance dredging of the authorized Delaware River tributaries.

Since the first authorization of the Delaware River project and major tributaries about one billion cubic yards of material have been removed. Extensive use has been made of the tidal marshes for disposal of the material. Many valuable industrial sites have been created. As previously stated, the tidal marshes along the estuary are rapidly disappearing. Between Philadelphia and Trenton, marshes are practically nonexistent. The few remaining are, for the most part, being reserved for wildlife habitat. There are still extensive marshes between Wilmington, Delaware, and the Sea; however, many of these are also reserved for wildlife habitat. The problem shoaling areas are located upstream of Wilmington, Delaware. Presented in Tables V and VI are the quantities of material removed from the Delaware River, Schuylkill River, and Wilmington Harbor, based on the District records.

TABLE V

Project	Date Authorized	Fiscal Year Dredged (1)	QUANTITY (c.y.) New Work	QUANTITY (c.y.) Maintenance
PHILADELPHIA TO THE SEA Improvement of Phila. Harbor prior to 1885 authorization		1874-1885	3,467,000	
26' & 30' Channels - Phila. to Sea	1885, 88&89	1886-1909	51,470,000	
35' x 1000'-1200' Channel - Allegheny Ave. to Sea	1910	1910-1930	49,424,000	
Port Richmond, Mantua Creek and Gloucester Anchorages	1930	1930-1934	8,645,000	
Marcus Hook Anchorage - 35'	1935	1935	2,878,000	
37' Channel - Phila. to Navy Yard - 40' Channel to Sea	1938	1940-1945	53,380,000	
37' Channel - Allegheny Ave. to Benj. Franklin Bridge & Port Richmond Anchorage	1945	1959-1960	1,102,000	
Enlargement of Marcus Hook & Mantua Creek Anchorages - 37' deep	1945	1947-1957	9,850,000	
40'x400' Channel - Allegheny Ave. to Naval Base	1954	1962-1963	4,451,000	
40' Anchorage - Marcus Hook	1958	1964-1964	16,686,000	
Maintenance Dredging		1911-1967		592,556,000
TOTAL			201,353,000	592,556,000 (2)
(2) 21,016,000 c.y. accomplished by contract.				
PHILADELPHIA TO TRENTON 7'x200' Channel - Not definite project prior to 1910		1874-1910	497,000	
12'x200' Channel	1910	1911-1922	2,774,000	
20'x200' to 300' Channel	1925	1930-1933	5,100,000	
28'x300' Channel - Allegheny Ave. to Delair Br.	1930	1931	218,000	
25'x300' Channel - Delair Bridge to Trenton	1933&35	1933-1937	9,263,000	
40'x400' Channel - Allegheny Ave. to Newbold is.	1954	1957-1964	36,345,000	
Maintenance Dredging		1914-1967		14,572,000
TOTAL			54,197,000	14,752,000 (2)

(1) This table thru 1967.
(2) 11,387,000 accomplished by contract

TABLE V

TABLE VI

Project	Date Authorized	Fiscal Year Dredged	QUANTITY (c.y.) New Work	QUANTITY (c.y.) Maintenance
SCHUYLKILL RIVER				
20'x100' Channel - Mouth to Gibson Point	1870)			
24'x300' Channel - Mouth to Girard Point	1875)	1870-1891	1,765,000	
24'x 400' Channel - Mouth to Girard Point	1883)			
20'x250' Channel - Gird Pt. & Gibson Pt.	1892	1895-1917	3,066,000	
35'x400' to Girard Pt., 33'x250' to Gibson Pt. 22'x200' to University Ave. Bridge	1917	1919-1923	4,054,000	
33'x400' Mouth to Girard Pt., 35'x400' to Passyunk Ave. Br., 26'x200' to Gibson Pt. and 22'x200' to University Ave. Bridge	1946	1948-1966	3,463,000	
Maintenance Dredging				40,275,000
TOTAL			12,348,000	40,275,000
WILMINGTON HARBOR				
12'x200' Channel	1870	1873-1881	252,000	
15'x200' Channel	1881	1882-1884	1,000,000	
21'x200' Channel	1896&1899	1896-1901	2,463,000	
25'x400' Channel and Turning Basin	1922&1925	1924-1925	3,397,000	
30'x400' Channel and Turning Basin	1930	1931	792,000	
35'x400' Channel and Turning Basin	1960	1962	1,736,000	
Maintenance Dredging				57,360,000
TOTAL			9,640,000	57,360,000

TABLE VI

X PLANS FOR FUTURE DEVELOPMENT OF PORT

BACKGROUND - The Port of Philadelphia handles well over 100 million tons of cargo annually. Based upon total tonnage handled, the Port ranks among the world's top five ports, second in this nation only to the Port of New York.

The cargo consists mainly of bulk commodities such as ore, petroleum, coal, chemicals, sand, gravel and similar cargo. About 3 percent of the total tonnage handled is general or packaged cargo, yet general cargo is a vital factor in the economy of the Delaware Valley region.

In contrast, other major world ports handling large cargo volume develop general cargo movement to a much higher degree than Philadelphia. The potential is far greater provided the terminal facility system is available to attract and efficiently handle it.

The Port of Philadelphia is well served by each mode of transport. Railroads dominate the movement of bulk cargoes, while trucks handle better than two-thirds of general cargoes. Service in the Port is regularly scheduled to world-wide points. However, the lack of first and last port calls by ships tends to reduce the general cargo value.

Future development of the facilities of the Delaware River cover a wide range and include possible widening and deepening of the authorized channel, provision for new anchorages, construction of marine terminals and marinas, and investigation of off-shore unloading facilities. Various agencies such as the Federal Government, municipal governments, the Delaware River Port Authority, the Port Corporation, the States of New Jersey, Pennsylvania and Delaware, and private industry are deeply concerned about the continued growth of the port facilities.

PORT AUTHORITY - The Delaware River Port Authority is an organization authorized by the Commonwealth of Pennsylvania and the State of New Jersey to provide for the development and improvement of the port district; promote the Delaware River as a highway of commerce; cooperate with all other bodies interested in or affected by the promotion and development of the Delaware River and port district; promote a high speed system of mass transit for southern New Jersey; and erect and operate necessary river crossings between the City of Philadelphia or the County of Delaware in the Commonwealth of Pennsylvania and the State of New Jersey.

In a report published in April 1967, the Port Authority presented its plans to develop marine terminal facilities in the cities of Camden, N.J. and Chester, Pa., representing their short range plans for development of the port. In addition, the Port Authority plans to construct a high-level, eight-lane vehicular crossing between Delair, New Jersey, and Philadelphia, Pennsylvania, and another six-lane highway bridge between Chester, Pennsylvania and Bridgeton, New Jersey.

The design criteria for the two terminals include providing large acreage facilities with marginal or some marginal berth bulkheads, prime access to rail and highway transportation, and flexibility to accommodate new development. These two terminals will provide a marine terminal capacity of 3,750,000 tons.

CITY OF PHILADELPHIA - The City of Philadelphia has constructed a solid fill wharf at Greenwich Point, called Packer Terminal. This facility extends southward from the Walt Whitman bridge, providing 2,035 feet of offshore frontage and dredging between the channel and the wharf to a depth of 39 feet.

The City of Philadelphia also has under construction the Penn's Landing project, to include a recreational complex and commercial structures, in the Delaware River in the one-mile waterfront area between the Benjamin Franklin bridge and Catherine Street, Philadelphia. The Penn's Landing project will provide a marginal berth for cruise ships, a historic ship basin, a small boat basin, and an embarcadero along a bulkhead fill area. A science museum, a modern port office building, port-oriented commercial buildings, restaurants and possibly apartment buildings will be constructed along this river-front area adjacent to the Delaware Expressway. These port facilities are not intended for commercial navigation. Construction of the project commenced in 1967. The navigation facilities and appurtenant structures are scheduled for completion by 1973 and the overall project is scheduled for completion by 1976, the Centennial year.

PHILADELPHIA PORT CORPORATION - This corporation, which was recently formed to promote water-borne commerce of the Port of Philadelphia, to acquire, maintain and modernize the Port's existing facilities for the handling of cargo, and to design, construct, lease or otherwise acquire, maintain and modernize new facilities for the development of the Port's cargo handling potential, is also constructing terminal facilities. This terminal, known as Tioga Terminal, will provide 2,400 lineal feet of berthing and will extend from Pier 181 north to the Philadelphia Electric Company property. It will also include a 100,000 sq. ft. transit shed and 7.1 acres of open storage for each of four berths. In addition, the Port Corporation has received approval to initiate action toward producing a ship terminal on the Schuylkill River to be known as the Penrose Ferry Terminal.

The Delaware River Joint Toll Bridge Commission, acting on behalf of a bi-State area comprised of Burlington and Mercer Counties in New Jersey and Lower Bucks County in Pennsylvania, retained Walter P. Hedden, a port development consultant of New York City, to prepare a program of marine development. The Hedden report recommended a three terminal construction program, including reconstruction of the Trenton Marine Terminal and construction of facilities in Bucks and Burlington Counties, and proposed operation by the Delaware River Joint Toll Bridge Commission. These plans have not been expedited since Congressional approval has not been granted authorizing expansion of the Commission's activities to include port operation. It was also recommended in "Zoning of Industrial Land in Port Areas", a report prepared as an aid to development of Mercer County's waterfront, that the available land in the vicinity of the Marine Terminal and Duck Island be set aside for port industry development, with adjacent meadow lands being set aside for conservation. The greater Trenton area, in addition to being involved with the above plans, has petitioned the Federal Government to complete the dredging upstream of Newbold Island to the project depth of 35 feet. The failure of the Federal Government to provide funds for this work is, to a degree, attributable to the fact that a 25-ft. depth channel to Trenton was established in the 1930's, and in the 1960's and each of these deepenings failed to stimulate any deep draft commerce. Commerce consistently continues to be of the barge type and approximate 16-ft. channel depths to Trenton are maintained.

XI PRIVATE DEVELOPMENT

Local interests are encouraging improvement of the channel to include deepening the channel to 50 feet between Allegheny Avenue and the Sea, and widening to between 1,000 and 2,000 feet with suitable widening at bends. More specifically, the recommended widths are:

a. Bay area - 2,000 feet

b. Liston Range - 1,200 feet

c. Baker Range - 1,800 feet

d. Reedy Island and New Castle Ranges - 1,000 feet

e. Bulkhead Bar Range - 2,000 feet

f. Deepwater Point Range - 1,000 feet

g. Cherry Island Range - 1,000 feet

h. Lower Marcus Hook Range - 1,000 feet

i. Upper Marcus Hook Range - 1,500 feet

j. Chester, Eddystone, Tinicum Ranges - 1,000 feet

k. Billingsport - 1,100 feet

i. Horseshoe Bend - 1,500 feet

m. Philadelphia Harbor - 1,000 feet

The above features were recommended by the Joint Executive Committee for the Improvement and Development of the Philadelphia Port Area at the public hearing for the Delaware River, Philadelphia to the Sea, Channel Dimension and Anchorage Study, held in April 1965. Their proposal, which represents the opinion of its 18 member organizations, also recommended realignment of the existing channel in some cases and suitable widening at bends. The following recommendations were made regarding anchorages.

1. Provide a new anchorage 5,000' x 2,400' on the easterly side of Liston Range between Bell buoys No. 6L and No. 8L.

2. Relocate the explosives loading area adjacent to the existing facility on either the north or south side, thereby making the present anchorage which is regarded as one of the better areas available to general shipping.

3. If the above is not feasible, extend the present anchorage on the east side of New Castle Range opposite Pea Patch Island to 5,000' x 2,400'.

4. The widths of the Deepwater Point and Mantua Creek Anchorages be increased to 2,400 feet.

5. Marcus Hook Anchorage be enlarged to 15,600' x 2,400'.

6. A depth of 47 feet be provided in all anchorages except in the Port Richmond and the Gloucester Anchorages, with present project dimensions being provided at the latter anchorages.

The above recommendations have been indorsed by the Delaware River Port Authority and various other private interests.

In addition to the above, the AMMI, American Merchant Marine Institute, Inc., which is a national trade association composed of 42 companies in the United States owning and operating 5,700,000 gross tons of ocean-going vessels, has recommended the following improvements:

a. The channel depth between Allegheny Avenue and Newbold Island be increased to 45 feet.

b. Increase the width of the channel to 500 or 600 feet for proper navigation of two-way traffic.

c. Widen bends in the channel to 700 or 800 feet, depending on the angle of intersection.

d. Deepen Port Richmond Anchorage to 45 feet.

e. Replacement of the Tacony Palmyra Bridge, thus removing the hazardous bottleneck caused by the bridge.

Private concerns have already constructed many large terminals and many are considering future expansions. The docking facilities of Delaware Terminal, Inc. consists of a solid fill marginal wharf with 700 feet of offshore frontage extending along the pierhead line between Allegheny Avenue and Pier 179 north, and includes dredging channelward of the wharf to a depth of 32 feet. The National Sugar Refining Company has approximately 800 feet of bulkhead between piers 44 and 50 north (in the vicinity of Shackamaxon Avenue). The Northern Metals Company provides a solid fill wharf extending 1,200 feet along the pierhead line in the vicinity of Milnor and Bleigh Streets, and includes dredging channelward of the wharf to a depth of 40 feet. In addition, the Rohm & Haas Co. has applied for a permit to construct a 4,280-ft. long solid fill wharf paralleling the ship channel and approximately 250 feet landward thereof between Buckius Street and Frankford Creek.

Ten major oil companies have formed a consortium, known as the Delaware Bay Transportation Company, to consider the feasibility of constructing a deepwater terminal facility in lower Bay to accommodate large oil tankers. The terminal being considered will be located approximately four and a half miles offshore in the vicinity of Big Stone Beach, Delaware. The project consists of marine mooring facilities; pipelines from berths to tank farm areas; mammoth tank vessels, and barges and tow boats or pipelines to transport the crude oil to the various refineries in the Philadelphia area. The total cost for these facilities is estimated at $250,000,000.

The present controlling depth of 62 feet would limit vessels to those having a 54-ft. draft, since 10 feet is required for floatation. However, a channel 72 feet deep and 2 miles long could be opened between two natural deep areas which would permit vessels with drafts of 62 feet.

It is estimated that the quantity of oil which would be handled at the terminal would be approximately 500,000 barrels per day and result in an estimated annual saving of $2,400,000.

The feasibility plan for the terminal facilities has been completed and is now under consideration by the participating corporations. If approved, the target date for completion and operation of the facilities is 1970.

XII FEDERAL DEVELOPMENT

The federal Government has been and will continue to be responsible for providing and maintaining the authorized projects in the Delaware River and its tributaries. It also has the responsibility of continually investigating present authorizations in an effort to determine if larger dimensions for channels and anchorages are warranted.

Currently a study is being made to investigate the need for enlarging the present channel dimensions. In connection with this study, public hearings have already been held for the portion from Philadelphia to the Sea (20 April 1965) and Philadelphia to Trenton (20 April 1966) to determine the views of other interested parties. Various municipal, county, state and Federal government officials and representatives of public utilities, unions, steamship lines and agents, commercial interests, organizations such as the AMMI, JEC, Delaware River Port Authority, Philadelphia Port Corporation, and other interested individuals attended these hearings in an effort to express their opinions. Their combined views and recommendations were presented in the preceding two sections. At any rate, the future plans of the Federal Government at this time are to finish the uncompleted portions of the previously authorized projects as described in section V and to complete the Channel Dimension Study. Other studies, as outlined in the Appendix are also being investigated by the Federal Government in an effort to increase our knowledge of the problems and characteristics of the Delaware River.

The Federal Government has recently become involved with various small navigation projects and marinas along the Delaware River. The small navigation projects include maintaining an access channel for local industries in the vicinity of Delaware City, Delaware, and providing an access channel and anchorage at Tinicum Island back channel. The former project arose as a result of a request from the Tidewater Associated Oil Company to maintain an access channel between the main channel and their facilities. They had already provided a channel 40-ft. deep, 400-ft. wide, and approximately 3 miles in length, including a 3,500-ft. - 5,500-ft. x 800-ft. x 35-ft. turning basin. In view of the fact that additional industries, namely, the Diamond Alkali and Stauffer Chemical Company are moving to a point approximately one mile upstream, the channel no longer benefited a single user and, hence, could be considered as a federal project. As a result, the Government proposed to dredge a 250-ft. x 35-ft. channel extension approximately one mile in length, including a turning basin at the upstream end of the channel, providing that local interests furnish an adequate disposal site for new work and maintenance material. No work has been done as assurances for the above and other local cooperation requirements have not been furnished.

The project involving the Tinicum Island back channel is presently in the process of being investigated as a result of requests from local interests. They claim that silting which has occurred outside the natural back channel and in the upper end of the back channel in the vicinity of the Westinghouse property is the result of the Federal dredging operations in the main channel. A plan which would provide an entrance channel between the main channel at the downstream end of Tinicum Island and the portion of the back channel that has not silted and also provide an access channel and anchorage adjacent to the back channel is being considered. In connection with this project, an additional entrance channel would be cut across Tinicum Island, adjacent to the upstream end of the deeper portion of the back channel and the areas upstream thereof, including the shoaled portion of the back channel, and upper Tinicum Island would be used as a disposal area.

The Federal Government is involved in various stages of investigation or construction of the Neshaminy State Park, Philadelphia (Hog Island) and Bristol Marinas. Other marinas which, at this point, have only been discussed informally have been proposed at Pettys Island, Burlington Island, and near Neshaminy Marina. The Federal portions of the project at Neshaminy Marina have just been completed. It is located on the Delaware River immediately upstream of the mouth of Neshaminy Creek in Bucks County, Pa. The general navigation facilities include a 60' x 350' entrance channel, a 150' x 160' major access channel, a 100' x 691' access to the turning basin, a 200' x 200' turning basin, 675 feet of stone revetment, and a 230-ft. long stone jetty, and has a project depth of 8 feet. The Philadelphia Marina is located in Tinicum Township on an area formerly occupied by the Hog Island Shipyard in the vicinity of the Philadelphia International Airport. This project, which will shortly be in the initial construction stages, will include general navigation facilities such as a 100' x 500' entrance channel, a 1,200' x 1,850' access and maneuvering area, a 100' x 850' anchorage, and a project depth of 8 feet. The preparation of the Detailed Project Report for the Bristol Marina has been initiated. The proposed project is to be located along the Delaware River in the borough of Bristol opposite Burlington Island. Other details are not yet available. The extent to which Government participation is involved is or will be described in the detailed project reports for each of the above projects and generally includes 50% of initial cost and all of the maintenance costs for the general navigation facilities. Local interests are to provide the remainder of the facilities as required to complete the projects.

APPENDIX A

STUDY OF SHOALING IN THE DELAWARE ESTUARY

BY
C.F. WICKER

TABLE OF CONTENTS

INTRODUCTION

PURPOSE OF THIS PAPER

1. The U.S. Army Engineer District, Philadelphia, proposes to undertake a study of the problems involved in maintaining the navigation channels and anchorages of the Delaware Estuary. Part of the investigation will consist of a study of the mechanics involved in the scour, transport, and deposition of sediment and the sources of the shoaling material. A panel of consultants having expert knowledge of the factors involved will be assembled to assist in the planning of the study. This paper has a two-fold purpose: 1) To acquaint these consultants with information on the characteristics of the estuary, to facilitate their considerations; 2) To propose a program of study, solely to promote discussion and to serve as a point of beginning for the formulation of their recommendations.

PROBLEM

2. The navigation channels and anchorages of the Delaware are subject to heavy recurring shoaling. Much of this is concentrated currently in reaches where disposal areas are scarce, and the time is approaching when the available areas there will be filled to capacity. A comprehensive study is proposed, consisting of five parts (designated as "Sub-studies") as follows.*

> SUB-STUDY #1: This study is designed to obtain enough disposal area capacity to meet the requirements of the next ten years. It appears that this is taking the direction of developing so-called riparian areas, which are generally in the shallows along the shores.
>
> SUB-STUDY #2: This study is proposed for the purpose of developing basic data as to the causes of shoaling, the nature of the deposits, and the sources of the material of which they are composed. With a better understanding of the processes involved, it is hoped that it may be possible to ascertain whether it is feasible to reduce the total amount of shoaling, but if not, whether other means exist whereby the locations of the shoals may be shifted to places where disposal area capacity may be made available for the foreseeable future. (This is the Sub-area that is of primary concern in this paper, and to the panel of consultants to whom it is addressed.)
>
> SUB-STUDY #3: This part of the overall investigation is intended to deal with the development of new dredging equipment and techniques.
>
> SUB-STUDY #4: This Sub-study is proposed for the purpose of developing methods for long distance pumping, assuming that means for causing shoals to shift to locations where there is much disposal area potential cannot be economically developed.
>
> SUB-STUDY #5: This part of the comprehensive investigations has for its purpose the examination of the economic feasibility of river training works by means of tests using the existing Delaware Estuary model to encourage shifting the shoaling to more desirable areas for disposal.

3. In addition to the problem of the shoaling of the navigation channels and the appurtenant anchorages, the matter of tur-

*The study resulted in a report in seven parts as listed in the Forward, page i.

bidity of the waters of the estuary is of concern from the viewpoints of recreational interests and those concerned with finfish, shell fish, and waterfowl. If the sources of shoal material can be located and either eliminated or their contributions reduced, it follows that water turbidity will be reduced with benefits to both navigation facilities and other matters mentioned. On the other hand, it is conceivable that the most economic solution of the maintenance of navigation facilities would not reduce the turbidity of the water. If, for example, means can be developed at an economic cost that will cause the shoals to shift to another location, it follows that water turbidity will be increased in the intervening reaches.

4. The total scope of the proposed investigation has been described briefly to indicate the awareness that the solution of the problems described may consist of combinations of methods to reduce the amounts of sediments contributed, the transfer of the locations where most of the sediments accumulate as shoals, and advanced methods for removing the shoals in the most economic manner. As stated above, the consultants to whom this paper is presented are expected to address most, if not all, of their attention to Sub-area #2, which has to do with sources of shoaling material and the mechanics of scour, transport, and deposition of sediments in the environment of the Delaware Estuary. As they may not be familiar with the characteristics of the estuary and of the factors that are significant to the problem, these are described briefly below.

GENERAL DESCRIPTION OF THE ESTUARY

GEOMETRY

5. Plates 2, 3 and 4 show the configuration of the estuary and furnish descriptions of the authorized and constructed navigation channels and appurtenances. Plate 7 supplements these maps by means of graphs of mean depth, cross-sectional areas, and widths at approximately mean tide for the latest hydrographic surveys available. Its mouth is a little over 11 miles wide, then the width progressively increases to a maximum of about 26 miles, thereafter it decreases at a fairly uniform rate to a minimum of 800 ft. at the head of tide, which is located 132 miles above the mouth, at Trenton, New Jersey. The cross-sectional area increases from 2,900,000 sq. ft. at the mouth to 3,300,000 about 15 miles upstream, then decreases at a remarkably uniform rate to a minimum of 6,300 sq. ft. at the head of tide. The mean depth varies somewhat erratically (compared with the variations of width and cross-sectional area) from a maximum of 48 ft. at the mouth to a minimum of about 9 ft. at Trenton. However, it strikes a fair average of about 20 ft. from Mile 15 above the mouth to Mile 125. The maximum depth along the thalweg occurs a short distance above the entrance, where depths of the order of 150 ft. are encountered. Thence, the maximum depths are generally about 40 ft., corresponding to the depths of the dredged navigation channel, to a point 6 miles below the head of tide. From here, the maximum depths (again, in the dredged navigation channel) are 25 ft. for a distance of about 5 miles and 12 ft. for the remainder.

6. In the 132 mile length of the estuary, there are only 10 islands where back channels exist. Of these back channels, four are of some significance, four others are of little significance, and two are of no significance. In summary, the Delaware has remarkably simple geometry in compari-

son with most estuaries. The main channel carries most of its discharges, and there are few abrupt changes of width and cross-sectional area.

7. In its natural state, prior to undertaking the first improvements (1836)(1) the controlling depths from the mouth to Philadelphia, a distance of about 100 miles, were of the order of 17 ft., (2) and from Philadelphia to Trenton the controlling depth was 3 ft.(2) The current state of the channel improvements in the interest of navigation is as follows:

REACH	CHANNEL DIMENSIONS
Mouth to Mile 6	Natural depths and widths adequate
Mile 6 to Mile 40	40 ft x 1000 ft
Mile 40 to Mile 96	40 ft x 800 ft*
Mile 96 to Mile 104	(40 ft x 400 ft (35 ft x 600 ft**
Mile 104 to Mile 128	40 ft x 400 ft
Mile 128 to Mile 133	25 ft x 300 ft***
Mile 133 to Mile 134****	12 ft x 200 ft

*800 ft width in this reach is increased at bends.
**Authorized depth is 37 ft but this has not been dredged.
***Authorization exists to increase this reach of channel from 25 ft x 300 ft to 35 ft x 300 ft, but this work has not been undertaken.
****Total distance of 134 miles shown is measured along the improved channels; it is about 2 miles greater than the length along the midstream line.

In addition to these channel improvements, four anchorages have been created and two others are authorized but not constructed. Those in existence are listed below:

Anchorage	Location (Miles above Mouth)	Existing Dimensions		
		Width	Length	Depth
Marcus Hook	81	2300	13,650	40
Mantua Creek	92	1400	11,500	37*
Gloucester	96	550	3,500	30
Port Richmond	103	750	5,800	35

*Authorized dimensions are 2300 ft in width, 11,500 ft long and 40 ft deep.

(1)Reference page .
(2)Reference page .

8. A study is currently underway at the request of local interests to increase the dimensions of the channel from the mouth to about Mile 37 above the mouth to a depth of 50 ft. and a width of 2,000 ft., and thence to Mile 52 the least width would be 1200 ft.; from here to Mile 94, the least width would be 1000 ft., and the depth throughout would be 50 ft. The channel depth would be increased from 40 ft. to 45 ft. from Mile 94 to Mile 128 with no change in the general width (some widening at bends), according to the views of interested parties. In addition, the dimensions of the existing and previously authorized dimensions of the anchorages would be increased, if the views of local interest are adopted.

CHARACTERISTICS OF THE BANKS OF THE ESTUARY

9. The following tabulation summarizes the characteristics of the shorelines of the estuary.

Reach	East Shoreline	West Shoreline
Mouth to Mile 52	Natural condition; tidal marshes up to 5 miles in width.	Natural condition mostly; tidal marshes up to 5 miles in width.
Mile 52 to Mile 58	Includes 3 miles bulkheaded shoreline and filled ground, and about 3 miles natural marsh.	Natural conditions; narrow belt of tidal marsh; Unprotected Reedy Island west of main channel.
Mile 58 to Mile 62	Mostly natural condition; tidal marsh up to mile wide.	Mostly protected shoreline, dredge disposal areas, large oil refinery; Unprotected Pea Patch Island west of main channel.
Mile 62 to Mile 67	Mostly protected dredge spoil areas and small river communities.	Mostly natural; narrow belt of marsh; small town.
Mile 67 to Mile 70	Mostly protected high ground; highly industrialized.	Mostly protected; dredge spoil areas; small town.
Mile 70 to Mile 74	About 50% protected, mostly high ground.	Protected dredge disposal areas.
Mile 74 to Mile 79	Natural or filled ground; little marshlands; mostly unprotected.	Mostly unprotected high ground; fall line from Mile 74 to Mile 134 sometimes close to shoreline.

Reach	East Shoreline	West Shoreline
Mile 79 to Mile 86	Many dredge disposal areas, banks generally unprotected; unprotected Chester and Monds Islands east of main channel.	Mostly protected high ground; highly industrialized; large communities of Marcus Hook and Chester.
Mile 86 to Mile 89	Mostly bulkheaded; filled ground; many industries.	Mostly bulkheaded; small town; industries; unprotected Tinicum Island west of main channel.
Mile 89 to Mile 94	Mostly unprotected filled ground.	Piers and bulkheads.
Mile 94 to Mile 102	City of Camden; mostly bulkheaded, about 1/3 filled ground, remainder high; piers and industry.	Naval Base and City of Philadelphia; piers and bulkheads; mostly high ground.
Mile 102 to Mile 108	About 50% bulkheaded; much high ground some fills; Petty Island, east of main channel, mostly bulkheaded fill; industry.	City of Philadelphia, piers and bulkheads, high ground, industry.
Mile 108 to Mile 112	About 50% natural high ground remainder filled marsh; little protection; several residential communities.	City of Philadelphia; mostly bulkheaded high ground; industry.
Mile 112 to Mile 119	Mostly high ground, about 50% protected. Several residential communities and industry.	Mostly natural high ground, largely unprotected. Dredge spoil areas, unprotected banks. Unprotected marshy Mud Island west of main channel.
Mile 119 to Mile 122	Town of Burlington; mostly high ground, protected. Unprotected Burlington Island with dredge spoil fill east of main channel.	Town of Bristol; high ground, mostly protected.

Reach	East Shoreline	West Shoreline
Mile 122 to Mile 126	Unprotected bluffs; industry. Small town.	Natural shoreline, little protection. About 50% high ground, remainder marsh.
Mile 126 to Mile 128	Natural unprotected shoreline, high ground. Unprotected Newbold Island east of main channel.	Heavy industry; protected filled ground.
Mile 128 to Mile 134	Mostly unprotected natural high ground. City of Trenton.	Mostly unprotected natural high ground. Small town.

10. The distances tabulated above are measured along the navigation channel. It is probable that the total length of shoreline, exclusive of islands having significant back channels, is about 280 miles. Of this, about 45% is low and marshy, and about 50% of the total shoreline is unprotected by bulkheads or revetted slopes. All of the shoreline that is unprotected is composed of erodible materials.

CHARACTERISTICS OF BED OF ESTUARY

11. From the mouth to about Mile 40, the bed of the estuary consists largely of fine to coarse sand in the middle half, and generally of soft mud in the quarters along the shores. From Mile 40 to about Mile 95, the bottom consists largely of silt-size materials, although there are a few areas where fine sands are encountered, and in the reach from about Mile 79 to Mile 84 there are outcroppings along the westerly side of the navigation channel, and thence to the west shore of gneisses and schists. From Mile 95 to Mile 102, the materials encountered include some sands but mostly compact fines, but another outcropping of gneisses and schists occurs near the upper end of the reach. From Mile 102 to the head of tide, the bottom is composed of mud, sand and gravel, and there is a reach from Mile 111 to Mile 116 where the schists and gneisses again appear.

HYDRAULICS

FRESH WATER INFLOWS

12. The total drainage area tributary to the estuary amounts to about 12,765[3] square miles, excluding about 782[3] square miles of water surface. The non-tidal portion of the main Delaware above the Fall Line accounts for 6,780 sq. mi. of this total, or about 53%. The Schuylkill is the principal tributary of the estuary proper, entering at Philadelphia; it adds 1,909 sq. mi.[3] which is about 15% of the total drainage area of the estuary. The re-

[3]Reference page .

mainder (32%) is made up of numerous small tributaries, the largest of which is the Christina-Brandywine with 568 sq. mi.[3]; this enters at Wilmington. All of the watershed above Trenton and almost all of the drainage areas of the tributary streams entering from the west between Trenton and Wilmington, where the Fall Line turns to the west and leaves the watershed, lie within the physiographic province known as the Appalachian Highlands. The remainder of the drainage area lies within the Atlantic Coastal Plain. The total drainage area may be divided as follows:

Appalachian Highlands drainage area above Trenton	6,780 sq. mi.
Additional Appalachian Highlands drainage area	3,235 sq. mi.
Total Appalachian Highlands drainage area	10,015 sq. mi. (78%)
Total Atlantic Coastal Plain drainage area	2,750[4] sq. mi. (22%)
Total drainage area	12,765 sq. mi.

Most of the drainage area above the head of the estuary at Trenton was glaciated a number of times. Terminal moraines are found along several broad bands in the lower 30 miles of the watershed adjoining the upper limit of the estuary. In general, the region is rugged, well-forested, and the beds of the main stem and its tributaries are frequently paved with coarse glacial debris including boulders. The remainder of the Appalachian Highlands drainage area ranges from rugged to rolling, it is less abundantly covered with forests, there is much in use for agriculture, and extensive areas are urban or suburban. The Coastal Plain area displays slight relief, it contains numerous marshy areas, and the better-drained portions are extensively cultivated for agriculture, or for urban and suburban developments.

13. The mean discharge of the Delaware at Trenton is 11,910 cfs, with extreme high and low recorded discharges of 329,000 cfs and 1,220 cfs. Comparable data for the Schuylkill at Philadelphia are as follows: Mean, 2852 cfs; Maximum, 96,200 cfs; and Lowest, 284 cfs. The approximate mean rate of discharge at the mouth of the estuary, inferred from the above, is 20,200 cfs. The mean annual runoff is seasonally distributed as indicated below:

Month	Mean Monthly Discharges, cfs[5]		
	Delaware (Trenton)	Schuylkill (Philadelphia)	Brandywine (Chadds Ford)
October	6,000	1,400	200
November	11,100	2,300	400
December	12,500	3,000	450
January	12,700	3,500	530
February	12,800	3,700	670
March	22,600	5,200	730
April	23,100	4,100	660
May	14,500	3,000	560
June	8,900	2,000	410
July	7,600	1,700	310
August	6,500	1,500	350
September	5,700	1,600	250

(4)Reference page .
(5)Reference page .

Month	Mean Monthly Discharges as % of Total			
	Delaware (Trenton)	Schuylkill (Philadelphia)	Brandywine (Chadds Ford)	Weighted Average
October	4.2	4.2	3.6	4.2
November	7.7	7.0	7.2	7.6
December	8.7	9.1	8.2	8.8
January	8.8	10.6	9.6	9.1
February	8.9	11.2	12.1	9.5
March	15.7	15.8	13.3	15.6
April	16.0	12.4	12.1	15.1
May	10.1	9.1	10.1	9.9
June	6.2	6.1	7.4	6.3
July	5.3	5.2	5.6	5.3
August	4.5	4.5	6.3	4.5
September	4.0	4.8	4.5	4.2

14. The mean annual precipitation varies from a maximum of 58 inches[(6)] at the headwaters of the basin to a minimum of 40 inches[(6)] over Delaware Bay. The seasonal distribution and the precipitation-runoff relationships are tabulated below:

Month	Mean in Inches			Ratio of precipitation to runoff (Trenton)
	Precipitation			
	Basin Average*	Above Trenton**	Runoff** at Trenton	
October	3.15	3.2	1.0	31.2%
November	3.83	3.9	1.8	46.2
December	3.38	3.4	2.1	61.8
January	3.47	3.5	2.2	62.9
February	2.74	2.8	2.0	71.4
March	3.85	4.2	4.9	116.7***
April	3.62	4.0	4.8	120.0***
May	4.[illegible]9	4.3	2.4	55.8
June	4.06	4.1	1.4	34.1
July	4.79	4.8	1.3	27.1
August	4.68	4.7	1.1	23.4
September	3.75	3.8	0.9	23.7
Totals & av.	45.61	46.7	25.9	55.5

*Source, Ref. (7)
**Source, Ref. (8)
***In part due to melting snow.

(6)Reference page .

15. Runoff is affected by [illegible] existing reservoirs of significant size. Of these, three are used for New York City water supply, and are so operated that the diversions from the Delaware Basin are limited to 800 m.g.d. and releases during low flows are required. Three other reservoirs exist for purposes of flood control, and the remaining three are parts of hydroelectric projects. In addition to these nine reservoirs, authorization exists for the construction of six major reservoirs and a number of smaller reservoirs, also for the modification of two of the existing flood control reservoirs. When this comprehensive project is completed, runoff will be regulated to a much higher degree than in the past. There will be significant changes in average monthly discharges and reductions of flood discharges.

16. There is an existing diversion into the Delaware Basin from the adjoining Susquehanna River Basin, effected by the City of Chester. This amounts to [illegible] m.g.d. In addition, there are numerous industries and municipalities that rely on deep-well water for their sources of supply, and after use these are discharged into the Delaware. As stated before, there is an authorized diversion from the Delaware Basin to New York City, limited to 800 m.g.d., and there is a diversion of a maximum of 100 m.g.d. from the Delaware a few miles above Trenton.

TIDES

17. The Delaware is tidal to Trenton, a distance of 132 miles measured along the midstream line. Further progress of the tide wave is terminated by the Fall Line, which here consists of a rise in the bed of the river at such gradient as to be above the elevation of high tide in 2000 to 3000 ft. after the ascent commences. Because of the convergence of the banks towards the head of tide and the fairly high hydraulic efficiency of the waterway, the tide range is greater at the head of tide than at the mouth, as indicated below in the following tabulation. All of the data have been reduced to long-time mean values and are representative of the conditions that exist when mean fresh water flows occur, corresponding to existing geometry and existing fresh water discharges.

TIDAL DATA(9)

Miles above Mouth	Station	Mean Range Feet	Mean Tide Level Ft.*	Lunitidal Intervals** HWI, Hrs.	LWI, Hrs.	Duration of Rise, Hrs.
0	Mouth***	[illegible]	3.07	8.63	2.19	6.44
20****	Miah Maull LH	[illegible]	3.12	9.12	3.07	6.05
36****	Ship John LH	5.87	3.15	9.91	4.13	5.78
40	Woodland Beach	[illegible]	3.17	10.14	4.51	5.63
49	Artificial Is.	[illegible]	3.20	10.68	[illegible]	5.54
58	Reedy Point	[illegible]	3.22	11.44	5.82	5.62
66	New Castle	5.48	3.27	11.83	6.46	5.37
73	Edgemoor	5.70	3.32	12.12	6.86	5.26
79	Marcus Hook	[illegible]	3.36	12.51	7.35	5.16
85	Baldwin's	[illegible]	3.41	12.92	7.74	5.18
92	Fort Mifflin	[illegible]	3.47	13.29	8.24	5.03
99	Philadelphia	6.01	3.55	13.92	8.82	5.10

TIDAL DATA (Continued)

Miles above Mouth	Station	Mean Range Feet	Mean Tide Level Ft.*	Lunitidal HWI, Hrs.	Intervals** LWI, Hrs.	Duration of Rise, Hrs.
110	Torresdale	6.12	3.61	14.46	9.43	5.03
117	Burlington	6.43	3.91	15.71	10.21	5.50
122	Florence	6.54	4.04	15.34	10.52	4.82
126	Fieldsboro	6.82	4.19	15.55	10.98	4.57
132	Trenton	6.90	4.27	15.78	11.27	4.51
132.4	Head of tide	0				

Source, Reference(9)

*Referred to a fixed datum plane 2.90 ft. below MSL.

**Reference is to moon's transit over longitude 75° west.

***Inferred from Atlantic City as representative of mid-stream values.

****These observations are approximately at midstream; those at the remaining stations are on one shore or the other. The ranges of tide on the New Jersey shore in this reach are appreciably greater than those on the Delaware shore, due to the Gorioli Force.

18. The tides in the Delaware are semi-diurnal, with very little difference between the rises and falls. The graph of tide heights against time is sinusoidal (approximately) from the mouth to about New Castle; upstream of that station, the duration of rise becomes progressively more short than the fall, culminating with about 4½ hours rise against about 8 hours of fall at Trenton.

DISCHARGES (TIDAL PRISM AND FRESH WATER).

19. The following tabulation furnishes data on the mean fresh water discharges and the combined fresh water-tidal prism discharges at several points along the course of the estuary:

PRINCIPAL FEATURES OF THE REGIMEN

Miles above Mouth	Mean fresh water discharge (cfs)	Combined Tidal and Fresh Water Discharges			
		Mean flood Discharge (cfs)	Mean ebb Discharge (cfs)	Total flood Discharge (cf x 10^6)	Total ebb Discharge (cf x 10^6)
0	20,200			92,600	93,500
20	19,000			40,300	41,200
36	18,500	801,000	749,000	17,000	17,800
40	18,200	642,000	618,000	13,700	14,500
49	18,000	472,000	448,000	9,800	10,600
58	17,800	372,000	348,000	7,700	8,500
66	17,600	302,000	287,000	6,200	7,000
73	16,900	248,000	235,000	5,050	5,800
79	16,700	208,000	199,000	4,180	4,920
85	16,500	176,000	184,000	3,620	4,350
92	16,300	139,000	141,000	2,820	3,540
99	13,600	101,000	103,000	2,000	2,600
110	13,300	58,000	68,000	1,160	1,750
117	12,300	29,000	39,600	540	1,080
122	12,200	18,400	31,400	340	880
126	12,100	4,600	21,500	50	575
132	11,900	0 *	12,200	---	520
132.4	11,900	0	11,900	---	---

*From this point to the head of tide, there is no flood discharge as such; the flow is always ebb, but the magnitude varies. The location of the point where the flood ceases is dependent on the rate of fresh water discharge; that shown corresponds to the mean rate of fresh water discharge.

Source: Cubature computations by U.S.A.E. District, Philadelphia.

CURRENT VELOCITIES

20. The current velocities generated by the above discharges are functions of the magnitudes of the discharges, the durations, and the varying effective cross sectional areas. Because of the slowly changing durations of flood and ebb, the fairly constant relationship between the discharges and the effective cross sectional areas, and the generally erodible character of the bed and banks of the estuary, the resulting current velocities, in terms of the maxima for the various cross sections, are unusually constant from about Mile 40 to Mile 110, according to the results of cubature computations. The following tabulation lists the mean maximum ebb and flood velocities for this reach, also to the head of tide. Similar data for the reach below Mile 40 are not available, but it is likely that the results would be similar.

MEAN MAXIMUM CURRENT VELOCITIES

Miles above Mouth	Flood fps	Ebb fps
40	1.8	1.8
44	2.1	2.0
54	2.0	2.0
63	2.3	2.1
72	2.1	1.9
79	2.[illegible]	1.9
83	1.9	1.9
91	1.9	1.9
99	2.1	1.9
110	1.9	1.8
114	1.4	1.4
121	1.9	1.4
123	1.6	1.1
132	0	2.4

21. It is emphasized that the above current velocities are the average for the various cross sections; naturally, the currents at and near the thalweg are greater. A great many actual observations have been made at various depths in the vicinity of the thalweg. These indicate that the maximum velocities at or near the surface are generally of the order of 4 fps. The distribution in the vertical follows the usual shape of vertical velocity curves in non-tidal streams from the head of tide to about Mile 80, and from Mile 30 to the mouth. From Mile 80 to Mile 30, it is often found that the distribution of velocities in the vertical is much different from that observed in upland streams, due to the effects of salinity.

SALINITY INTRUSIONS

22. The Delaware Estuary is usually considered to be an excellent example of an estuary having a so-called well mixed type of salinity intrusion. According to Harleman-Ippen[10], estuaries having an "Estuary Number" of over 0.15, as defined by the equation given below, are of that type.

$$\text{Estuary Number} = \frac{P_t F_0^2}{Q_f\ T}$$

Where P_t = the volume of seawater entering the estuary on the flood tide.

$F_o = \frac{u_o}{(gh)^{1/2}}$ u_o is the maximum flood tide velocity in ft/sec at the ocean entrance and h is the mean depth *of the estuary.*

Q_f = Fresh water discharge.

T = Tidal period.

For a mean fresh water discharge at the mouth of 20,200 cfs, the Estuary Number computed by the above equation is 0.6, and that for an assumed extreme upland flood discharge of 400,000 cfs at the mouth is 0.3. It is obvious that the Delaware is indeed a well mixed estuary.

23. The term "well mixed" indicates that there is little difference between the salinities at the bottom as compared with those at the surface. In the Delaware, the maximum difference is about two parts per thousand (o/oo) when the surface salinity is 15 o/oo, but this difference decreases both upstream and downstream of the point where it occurs. In other words, the salinity regimen in the Delaware has little in common with the so-called wedge type of intrusion, where the water at the surface may be practically fresh water while the water at the bottom is virtually of ocean salinity.

24. The extent of salinity intrusion in the Delaware is governed largely by the rate of fresh water discharge. At times when the discharge of fresh water is very low, there is a trace of salinity at Philadelphia, but when the rate of fresh water is at its mean value, there is no intrusion above Mile 80. During relatively high fresh water discharges, there is no salinity above Mile 65. Graphs of salinity at surface and bottom versus location in the estuary show that the slope is much flatter during low fresh water discharges than at high fresh water discharges; the downstream end approaches ocean salinity a few miles above the mouth in both cases while the upstream end of the intrusion varies as to location, as previously indicated.

25. Insofar as shoaling is concerned, the effects of salinity intrusion that are *significant* are the effects on current velocity distributions in the vertical and the effect of saline water on flocculation. With respect to the former, there is a region in the Delaware where there is a tendency for the flood discharges at the bottom to predominate over the bottom ebb discharges. Ippen and Harleman[10] have investigated this phenomenon for the Delaware for mean fresh water discharges and found that there

is a "null point" at about Mile 52, which is at the downstream end of Artificial Island. The term "null point" is indicated to mean the location at which there is no flow preponderance of flood discharges over ebb. This study shows that the flood at the bottom predominates over the ebb at least as far downstream as Mile 41, but it did not carry out the computations beyond here to locate the second null point, downstream of which the ebb again predominates over the flood, as the necessary data were not available. There can be little doubt that the region of bottom flood predominance over bottom ebb is not continuous all the way to the mouth, as it has been found that such is not the case for the Savannah, Charleston Harbor, and Hudson River. The significant point is that the reach of bottom flood predominance over bottom ebb prevents the discharge of most of the sediment to sea, as the bulk of the transport is in the lower strata of the river. Recomputation of the location of the null point for an inferred very low discharge of fresh water amounting to 1,900 cfs indicates that there is no significant change in the location of the upstream null point. For the maximum discharge of record, the null point would be found far downstream, well into the wide waters of Delaware Bay.

26. With respect to the effect of salinity on flocculation, it has been found (11) that Mare Island Strait (San Francisco Bay, California) sediments are flocculated at salinities of 1 o/oo or greater. Mare Island Strait sediments are fairly similar to sediments in the Delaware, as may be seen from the following tabulation:

PARAMETER	MARE ISLAND STRAIT	DELAWARE
Median Diameter	2.5 microns	1.6 microns
Cation Exchange Capacity	24.5me/100g	25.5 me/100g
Principal minerals present	kaolinite montmorillonite	kaolinite montmorillonite

Salinites of 1 o/oo or higher are experienced in the Delaware from the mouth to Mile 90 during low fresh water discharges and to Mile 68 during median rates of fresh water discharge.

SHOALING AND DREDGING

SOURCES OF SHOALING MATERIAL

27. The sources of shoaling in the Delaware which are to be considered in this study are as follows:

- Erosion of upland areas and beds and banks of watercourses
- Scour of the bed of the estuary
- Erosion of the banks of the estuary
- Dredging
- Storm and sanitary sewer outfalls
- Natural organic processes, i.e., the accumulation of remains of marine organisms, vegetal and animal.
- Industrial pollutants
- The Atlantic Ocean

This listing acknowledges those sources which customarily have been considered as primary, and also acknowledges for consideration those sources which have been recently suggested as being of possible significance. For example, certain FWPCA data can be interpreted to conclude that almost 50% of the shoaling which occurs in the river can be traced to sewer discharges or industrial pollutants.

28. The suspended solids loads

introduced into the estuary by non-tidal streams have been measured as follows:

SEDIMENT STATIONS ON TRIBUTARIES OF DELAWARE ESTUARY[12]

Station Location	Drainage Area sq. mi.	Period of Record	Sampling Frequency*
Delaware River–Trenton	6780	9/49 to present	D
Crosswicks Cr.–Extonville	84	5/58 to 9/60	I
		2/65 to present	W
Neshaminy Cr.–Langhorne	210	11/56 to 7/58	I
Schuylkill River–Manayunk	1810	11/47 to present	D
Wissahickon Cr.–Fort Washington	41	10/63 to present	W
White Clay Cr.–Newark	88	8/63 to 12/64	W
		1/65 to present	M
Brandywine Cr.–Wilmington	314	12/46 to 9/61	D
		7/62 to 7/63	I
		7/63 to present	W
Maurice River–Norma	113	2/65 to present	W
TOTAL	9440		

*D - Daily
W - Weekly
M - Monthly
I - Intermittent

29. The total drainage area tributary to the estuary, exclusive of water surface area of the estuary itself, is 12,765 sq. mi. It is seen that data on the suspended sediment loads from 74% of the drainage area are available. The U.S. Geological Survey (12) estimates that the bed load approximates 10% of the suspended load, and using this assumption, also estimates of the contributions from ungaged upland streams, they compute the total contribution to the estuary from upland sources as about 2,166,000 tons per year. They convert this to cubic yards on the assumption that the estuary sediments have a dry specific weight of about 34 pounds per cubic foot, or one ton equals 2.18 cubic yards, and derive the figure of 4,724,000 cubic yards as the contribution from upland sources.

30. From the head of tide to Sta. +212 (Mile 56), the net change of the bed of the estuary beyond the limits of the channel and anchorages has been scour, although some of the intervening reaches have shoaled moderately outside of the channel. Below Sta. +212, the only comparable data available terminates at Sta. +275. In this reach, the net change beyond limits has been shoaling. The determinations are based on comparisons of the two latest surveys available; although these comparative surveys were not made in the same two years throughout, it is considered that the results are at least indicative of the trends. The following tabulation summarizes the data.

CHANGES OF BED OF ESTUARY
(Beyond Channel and Anchorage Limits)

Miles from Mouth	Channel Stations	Reach	Scour (-); Shoal (+) Cu. Yds./Yr.
132 to 105	-160 to 0+000	Phila. to Trenton	-1,609,000
105 to 59	0+000 to +212	Phila. to Bulkhead Bar Rge.	-1,022,000
59 to 52	+212 to +275	New Castle Rge to Baker Rge	+1,048,000
52 to 0	+275 to mouth	Liston Rge to Mouth, no data	
		Total scour	-2,631,000

Contributions from other sources listed in Paragraph 27 have not been evaluated, but it is seen that there is a net scour of the bed of the estuary down to and including the most downstream reach in which shoaling of the channel occurs in the amount of 2,631,000 cu. yds. per year.

SHOALING OF CHANNELS AND APPURTENANCES

31. The following tabulation summarizes the latest data available for the main Delaware Estuary Channels and Anchorages.

CHANNEL AND ANCHORAGE SHOALING(13)

Reach Channel Stas.	Miles from Mouth*	Channel Ranges and Anchorages	Annual Shoaling Rates, Cubic Yards: Total for Reach	Rate per 1,000 ft. of, Chan: Average	Median	Maximum
-153 to -150	131	Trenton–Cochran	57,000	19,000	17,000	33,000
-150 to -148	130	Cochran–Biles	–	–	–	–
-148 to -132	128	Biles–Whitehill	204,000	12,800	13,000	33,000
-132 to - 96	123	Whitehill–Landreth	428,000	11,900	11,000	31,000
- 96 to - 63	116	Landreth–Beverley	501,000	15,200	13,000	42,000
- 63 to 0	108	Beverley–Harbor	–	–	–	–
0 to + 4	103	Port Richmond Anchorage	95,000	NA	NA	NA
+ 4 to + 55	98	Phila. Harbor Rges.	–	–	–	–
+ 55 to + 77	88	W. Horseshoe–Billingsport	706,000	32,100	25,000	81,000
+ 61 to + 72	92	Mantua Creek Anchorage	430,000	NA	NA	NA
+ 77 to +113	83	Billingsport–Chester	413,000	11,500	10,500	36,000
+113 to +131	79	Chester–Marcus Hook	2,142,000	119,000	121,000	192,000
+118 to +131	81	Marcus Hook Anchorage	400,000	NA	NA	NA
+131 to +164	74	Marcus Hook–Bellevue	1,405,000	42,000	44,500	103,000
+164 to +167	71	Cherry Island	–	–	–	–
+167 to +175	70	Cherry Island	507,000	47,500	61,000	121,000
+175 to +188	68	Cherry Island–Deepwater P.	–	–	–	–
+188 to +221	63	Deepwater Pt.–Bulkhead Bar	1,022,000	31,000	31,000	100,000
+221 to +235	58	New Castle	792,000	56,600	57,000	178,000
+235 to Mouth		Baker, Liston, etc.	–	–	–	–
		Total	9,165,000			

* Miles shown are at mid-points of reaches.
- Signifies negligible shoaling.
NA Signifies not applicable.

32. The foregoing figures are based on computations of the changes of place volumes over periods of about five years adjusted by any dredging performed in the reach during the period. Specifically, they are not based solely on the amounts dredged. In other words, to take a hypothetical case for illustrative purposes, if a reach had 100,000 cubic yards less in place at the end of five years than it did at the beginning of that period, and if 500,000 cubic yards had been dredged during the period, the net shoaling would have been 500,000 - 100,000 = 400,000 cubic yards, or 400,000 ÷ 5 = 80,000 cubic yards per year. The volume dredged in the case of hopper dredges is based on reductions of the weight of the load in the hopper, determined by shipboard instruments, by a factor determined from measurements of the density of the load and the in situ density of the shoal. In the case of pipeline dredging, also bucket or dipper dredging, the volume dredged is based on surveys made of short reaches just before and after dredging.

DREDGING

33. Dredging is performed by U.S. Government hopper dredges and privately owned pipeline, dipper, and bucket dredges, also specially designed plant for the removal of deposits and the processing thereof for the production of commercial sand and gravel. Most of the work done by the privately owned dredges is performed under contract for the Corps of Engineers, but that performed for other clients is accomplished in accordance with regulations similar to those enforced for Government contracts.

34. The work of the hopper dredges account for most of the maintenance dredging. Their operations conceivably could be responsible for some shoaling, but every effort is made to minimize this. There are only three possible ways for a hopper dredge to cause increased turbidity of the water in the area of its operations: The trailing drags, which are supposed to suck up the the shoal material, could stir up some of the deposits and fail to suck all of the material thus disturbed; pumping could be continued beyond the point of overflow of the hoppers, causing the overflow of mostly fines back into the estuary; losses could occur in the disposal operation. The effect of the drags has not been fully evaluated; the practice of pumping beyond overflow is rarely used in the Delaware; the disposal operation is conducted in a unique manner in the Delaware. This consists of arrangements whereby the hoppers are pumped out directly into an enclosed disposal area, and there are no losses enroute. The solids are transported as a slurry containing much water. The water is discharged from the disposal area over a weir with a large length, such that the velocity of approach is low and the depth of flow is thin. The surface area of the disposal area is proportioned to the rates of inflow to assure a long detention period and presumably good settling characteristics. The solids outflow with the effluent water is observed frequently and steps are taken to reduce these amounts when they exceed 13 parts per thousand by weight of sample in excess of the density of the estuary water at the site of the dredging. The District is in process of reducing the 13 ppt limitation to 8 ppt in consideration of the lightweight material being customarily encountered.

35. Dredging by pipeline dredges, whether for the Corps of Engineers or other clients, always involves disposal in confined disposal areas under regulations similar to those prescribed for the disposal areas used by the Government hopper dredges, as described above.

36. Dredging by dipper and bucket dredges, again whether for the Corps of Engineers or for other clients, involves the the transport by scows to semi-enclosed rehandling basins. Within these basins, there is a pipeline dredge which discharges into a fully enclosed disposal area which is operated under regulations similar to those discussed above. The buckets and dippers undoubtedly disturb the deposits and some

of the material may be transported by the currents away from the site of the dredging, but this loss has not been evaluated. It is possible that the scows are sometimes filled beyond their scuppers, and it is also possible that the operator of the dredge does not always drop all of the load of the dipper or bucket into the scow. It is also possible that an occasional scow load is dumped inadvertently enroute to the rehandling basin. Inspectors make every effort to prevent such losses, but none of them have been fully evaluated.

37. The sand and gravel dredges, which operate above Philadelphia, wash the material during the processing operation, and the wash water is allowed to flow back into the estuary. Obviously, the operation of these dredges results in a net removal of material from the estuary, but the wash water does increase the turbidity of the water somewhat. These increases have not been evaluated.

EVALUATION

38. According to the U.S. Geological Survey (see Par. 29 hereof), the inflow of solids from the uplands amounts to 4,724,000 cu. yds. per year. In Par. 30, it is stated that the bed of the estuary scours at a total rate of 2,631,000 cubic yards per year. The sum of these two figures is seen to be 7,355,000 cu. yds. per year. In Par. 31, it is stated that the shoaling of the channels and anchorages tabulated amounts to 9,165,000 cu. yds. per year. In addition to this shoaling, there must be added the following:

Schuylkill River navigation channel shoaling	447,000 cu. yds per year
Big Timber Creek " " "	5,000
Salem River " " "	15,000
Mantua Creek " " "	13,000
Cooper River " " "	12,000
Racoon Creek " " "	4,000
Darby Creek " " "	3,000
Wilmington Harbor (Christina River) navigation channel shoaling	879,000
Channel behind Pea Patch Island	1,000,000 *
Shoaling of dock areas and slips	200,000 *
Total	2,578,000 cu. yds per year

* Not maintained by the Federal Government; volumes shown are approximate.

The shoaling of navigation channels and other areas, including the important tributary navigation channels listed, thus amounts to approximately 11,750,000 cu. yds. per year. Adding the shoaling beyond channel limits downstream of Channel Station +212, 1,048,000 cu. yrds. per year, the total shoaling becomes 12,798,000 cu. yds. per year, which is about 173% of the total of the estimated inflow of sediments from the uplands and the contributions resulting from scour of the bed of the estuary, a fact that leads to the following questions which cannot be answered fully at present:

a. Is the U.S. Geological Survey estimate of 2,166,000 tons of sediments per year from the upland reasonably correct?

b. Is the conversion factor of one ton equals 2.18 cubic yards of shoal reliable?

c. Is the estimate of the average annual volume eroded from the bed of the estuary reasonably accurate?

d. Is the estimate of shoaling of the navigation channels, anchorages, and other areas reliable?

e. How much shoaling takes place beyond channel, anchorage and other areas?

f. Which, of the other sources listed in paragraph 27, are significant contributors to the shoaling problem?

39. With respect to question a., it is noted that daily sampling of the inflow of sediment from the upland is accomplished for 8,904 sq. mi. of the total of 9,440 sq. mi. for which some data area available. The area for which daily sampling data are available amounts to about 70% of the total area tributary to the estuary. Assuming that the data are reliable, it would appear that a sufficiently large area is gaged to permit good inferences of the total inflow. However, it is possible that daily sampling may miss the peak discharge of sediment. Furthermore, it is well known that the high degree of turbulence that exists during flood flows results in very erratic movements of sediment, and perhaps nothing less than continuous sampling during floods is necessary to determine with reasonable accuracy the discharges of sediment during these occasions. It is likely that it is during a flood that the bulk of the annual inflow occurs. Also, the assumed rate of bed load movement at 10% of the suspended load may be low for flood conditions. Although the particulars of the U.S. Geological Survey methods for gaging the suspended sediment load were not available for analysis, it appears probable that any errors in the final estimate of 2,166,000 tons per year would place this figure on the low side.

40. With respect to question b., the conversion factor of one tone of sediment inflow equals 2.18 cubic yards of deposit is based on an assumed specific weight of 34 pounds per cu. ft., a value taken from Hudson River data. The conversion factor is evidently based on the following computation:

$$\frac{\frac{2{,}000 \text{ pounds}}{\text{ton}} \times \frac{34 \text{ pounds}}{\text{cu. ft.}} \times \frac{27 \text{ cu. ft.}}{\text{cu. yds.}}}{} = 2.18 \text{ cu. yds. per ton}$$

To clear up any question as to the meaning of the term "specific weight", this is considered to be the dry weight of the solids per unit volume of the deposit in place. It is to be noted that the relationship between specific weight and the in situ wet weight of the deposits per unit volume depends on the grain size, the grain specific gravities, and the compaction of the deposit. As these parameters of the deposit vary from place to place in the Delaware, it is not in order to assume a constant specific weight to compute the conversion factor. A graph based on a large number of samples from seven waterways, including the Delaware, showing the relationship between the in situ wet densities and the specific weights of deposits results in the following tabulation:

"In situ" density		Specific weight, lbs/cu.ft.			Conversion Factor, tons to cu. yds.		
gr./liter	lbs/cu.ft.	Maximum	Mean	Minimum	Minimum	Mean	Maximum
1100	68.7	21	13.0	8	3.53	5.70	9.26
1150	71.8	24	19.0	14	3.09	3.90	5.29
1200	74.9	30	25.5	20	2.47	2.91	3.70
1250	78.0	37	31.8	27	2.00	2.33	2.74
1300	81.1	42	36.5	32	1.76	2.03	2.31
1350	84.3	47	41.5	37	1.58	1.78	2.00

The deposits in the Delaware range through all of the densities tabulated, and there have been many determinations. However, there are few determinations of specific weight, and it can only be assumed that they may vary as indicated. The specific weight assumed by the Geological Survey of 34 pounds per cubic foot is probably often true, but not to the exclusion of some of the other values tabulated above, and the conversion factor would therefor be highly variable, and not a constant, as assumed.

41. With respect to question c., namely, whether the quantity of sediment derived from erosion of the bed of the estuary is reasonably accurate, it has already been stated that it is unfortunate that the two latest surveys from bank to bank that were used in the determinations were not the same two years throughout. As a consequence, it cannot be said with assurance that the changes are truly representative of present erosive characteristics. Another deficiency enters into the results because of the lack of information on the volumes of material removed by the sand and gravel dredges that operate in the Delaware above Philadelphia. It follows, therefore, that the indicated net erosion in the reach above Philadelphia is greater than that which contributes shoaling material.

42. With respect to question d., namely, whether the estimates of shoaling rates of navigation channels, anchorages, and other appurtenances are reasonably accurate, it is considered that the volumes are satisfactory for the purposes of further analysis of the problem of reconciling the differences between sediment contributions from all sources and shoaling.

43. With respect to question e., it has been found that the net change in the bed of the estuary between Trenton and Channel Station +212 has been erosion. This is not to say that there has been no shoaling in these reaches of the estuary other than in the main navigation channel and other areas improved for navigation, but insofar as the overall problem of reconciling differences between the contributions from all sources and shoaling, it is in order to assume that all of these contributions ultimately deposit in the channels and other navigation improvements, and outside of the channel below Station +212.

44. Concerning question f., "Which, of the other sources listed in paragraph 27, are significant?", these include the following: Erosion of the banks of the estuary; dredging; storm and sanitary sewer outfalls; natural organic processes; industrial pollutants; and the Atlantic Ocean. None of these sources have been fully evaluated, initial evaluation probes have been made for a few, and nothing has been done about the remainder. The initial probes that have been made are with respect to dredging, which is discussed in paragraphs 33 to 37, and with respect to the contributions by industry and sanitary and storm water sewers. The FWPCA indicates that the total solids discharged into the estuary by industry amounts to 695,000 tons per year, and that storm and sanitary sewers together contribute 574,000 tons per year. The FWPCA definition of total solids includes "solid particles and any substance in solution which may change into solid matter either by precipitation by combination with other solutions or material in the estuary or from reaction to the environment of the estuary." Data are not available for conversion of these solids to cubic yards.

45. When a correlation is to be made between the contributions from all sources and the shoaling, it is obviously necessary that all of the figures involved be reduced to some common measure. It is not sufficiently precise to say that the total shoaling amounts to 11,750,000 cubic yards per year when it is well known that the densities of the deposits removed from the various locations where shoaling is experienced vary through a considerable range. Although it is somewhat unorthodox to speak of shoaling and bed erosion in terms of tons per year, it will greatly facilitate correlations if this measure is adopted.

46. As an example of the kind of correlation possible if tons per year is adopted as the measure, the following tentative budget of sediment contributions and shoaling is presented.

SEDIMENT BUDGET

CONTRIBUTIONS OF SOLIDS			
Inflow from uplands		2,166,000	tons/yr.
Erosion of bed of estuary:			
Between Trenton and Philadelphia, 1,609,000 cu yds/yr at assumed average density of 1350 g/lit. and correction factor of 1/1.78		904,000	"
Between Philadelphia (Sta 0+000) and Station +212+000, 1,022,000 cu yds/yr at assumed density of 1250 g/lit. and correction factor of 1/2.33		439,000	"
Industry contributions		695,000	"
Sanitary and storm water sewers		574,000	"
Total from these sources, which do not include bank erosion, dredging, natural organic processes, and the Atlantic		4,778,000	"
SHOALING			
Shoaling of channels, anchorages, and slips:			
Between Philadelphia and Trenton, 1,190,000 cu yds/yr at assumed density of 1200 g/lit. and correction factor of 1/2.91	586,000		"
Between Philadelphia (Sta 0+000) and Sta +235+000 10,553,000 cu yds/yr at assumed density of 1200 g/lit. and correction factor 1/2.91	3,626,000		"
Shoaling beyond channel limits, Sta +212+000 to Sta +275, 1,048,000 cu yds/yr at assumed density of 1200 g/lit. and correction factor 1.2.91	360,000		"
Total shoaling, not including reaches downstream of Station 275, for which no acceptable data are on hand	4,572,000	4,572,000	"
Difference between contributions from sources indicated and total shoaling indicated		206,000	"

These figures show that the total contributions from the sources indicated exceed the total shoaling down to Station +275 by 206,000. When data on the contributions from the other possible sources are determined, and those included are refined, and when the total shoaling is defined more accurately, it seems reasonable that there will again be an approximate balance.

SUMMARY

47. The Delaware Estuary is notably uncomplicated as compared to many of the estuaries of this country. Its geometry varies fairly uniformly throughout its course, and there are few reaches where there are secondary channels to complicate its hydraulics. Its regimen also varies from reach to reach in a fairly regular manner, relatively speaking, including the rise and fall of the tides, the total discharges, and the resulting currents. its salinity intrusion characteristics also are simple when compared with those of many other estuaries. Although the inflows of fresh water vary through large extremes over the period of record, the variations in an average year are not so great as are found in many other estuaries. Nevertheless, the regimen is complicated, and any study contemplated with a view to explaining the shoaling will be difficult to accomplish.

48. There are very important channel improvements in the interest of navigation in existence, and it is possible that further improvements will be undertaken. It is seen that the channels, anchorages, and areas at slips and docks shoal very seriously; the average annual shoaling from Trenton to a point about 58 miles above the mouth, including the major tributary channels, amounts to about 11,700,000 cubic yards. This does not accumulate uniformly in the affected reaches, but instead tends to concentrate in certain areas. In some cases, there is no shoaling in reaches between adjoining reaches where the shoaling is heavy. An especially important fact concerning the shoaling is that about 66% of the total occurs in a portion of the estuary where the shoreline is extensively developed and consequently there is presently a scarcity of existing or potential disposal areas. It is a certainty that this situation will become worse in the future as a result of further development of the shoreline and contiguous areas anticipated. At the present time, it is not possible to conclude whether the further improvement of the navigation channels and appurtenances desired by local interests will appreciably increase the quantity of maintenance dredging required, but this is certainly a possibility

49. It has been shown that there is a disparity between the amount of shoaling and the quantities eroded from the bed or transported to the estuary from the uplands. in terms of cubic yards per year, this amounts to 5,393,000, which is 173% more that can be accounted for by the contributions from these sources. In terms of the more precise measure of tons per year, the disparity is 1,049,000, which is 130% more than these contributions. These disparities are accounted for by the fact that contributions from other potential sources have not been evaluated, also because of deficiencies in the knowledge about the particulars of the shoal material, the material eroded from the bed of the estuary, and the contributions from upland sources. It is noted that in addition to the shoaling in the navigation improvements, there is some shoaling of the bed of the estuary beyond the limits of the channels and other navigation improvements. In the reaches above and including the most downstream shoaling of the navigation channel, the net change outside the channel is scour, but in the reaches downstream, to Station +275, the net change was shoaling outside of the channel, but

no appreciable shoaling takes place in the Channel (from Sta. +235 to the Mouth). There are no acceptable figures for shoaling beyond channel limits downstream of Station +275.

50. It is not possible to specify the causes of the shoaling precisely at this time. In the areas where shoaling is especially heavy, the average and normal maximum currents, in terms of the averages for the cross sections involved, are not notably different from those in adjoining areas where shoaling is light or even nonexistent. However, there are doubtlessly subtle differences. Although it is stated that the geometry of the estuary varies fairly uniformly from the mouth to the head of tide, it is nevertheless true that there are local departures from the form of a perfectly "regularized" estuary. Where the cross sectional area is somewhat deficient, there must be a somewhat higher current velocity regimen than where the cross sectional areas are somewhat excessive. If there is a close correlation between the competence of the currents and the available sediment load, a slight change in current velocity might cause erosion or shoaling, depending on the direction of the change. Another very important factor is the effect of salinity intrusions on the distribution of currents in the vertical and whether the flood at the bottom predominates over the ebb there. It so happens that the reach where the heaviest shoaling has occurred in the past five years has experienced somewhat greater salinities than are normal, due to the drought during that period. (It is to be noted that the shoaling data presented are representative of this period.) Although it is unlikely that the salinity in this reach has caused upstream predominance of the bottom flood currents over the ebbs, it doubtless has caused bottom currents that are appreciably lower than would normally be expected. As most of the sediment is probably transported in depths near the bottom, the competence of the currents would be decreased. Furthermore, flocculation could be a significant factor in shoaling in this reach.

51. It has been shown that shoaling occurs outside of channel limits downstream of the downstream end of the last reach where channel shoaling is experienced, but the total extent of this is not known. If this amounts to a considerable volume, or tonnage, it follows that there is a greater disparity in the sediment budget than that indicated. It is also to be kept in mind that the existing regimen of the estuary, corresponding to the existing spectrum of fresh water discharges, probably occasionally causes sediment to move downstream of the lower null point, due to freshets. This benefit (in terms of loss of sediment from the reaches where shoaling of the channel takes place) will be diminished when regulation of fresh water discharges as a result of the authorized reservoirs takes place. On the other hand, the reservoirs will intercept some of the sediment from the upland, and thus reduce the total contribution to be accounted for in a budget of sediment.

PROPOSED STUDY

52. The purposes of the proposed study are as follows:

a. To identify and evaluate all significant sources of the sediments that cause shoaling of the channels, anchorages, and other improvements made in the interest of navigation;

c. To obtain knowledge essential for estimating the shoaling of proposed modifications of the existing navigation channels and appurtenances;

b. To determine the causes of shoaling of certain reaches while adjacent reaches either scour or experience no net change;

d. To provide information leading to evaluations of the effects of the authorized reservoirs on the locations and rates of channel shoaling, for both the existing projects and those under consideration.

53. To these ends, the following studies are proposed. It is emphasized that the outline is submitted solely as a point of beginning for the discussions and ultimate formulation of conclusions by the consultants as to the best means for accomplishing the purposes stated above.

SOURCES OF SEDIMENT

54. a. Upland Contributions. Evaluate the U.S.G.S. sediment discharge observations, giving attention in particular to the frequency and scope of sampling during freshet and floods, also to the relations between bed and saltated loads to suspended loads. If these evaluations indicate the need, determine the natures of the improvements in technique desirable in concert with the U.S.G.S., and subsidize the making of more accurate determinations of the tonnages of inflow from the drainage areas above Trenton and on the Schuylkill at Manayunk.

b. Erosion of Bed of Estuary. In all reaches where erosion is taking place, obtain samples of the material from the upper parts of the bed and determine the specific weights. Compute, from the volume changes of the several reaches, the tonnages eroded and reduce to terms of tons per year. Adjust for the volumes removed by the commercial sand and gravel dredges.

c. Erosion of Banks of Estuary. Obtain aerial photographs of reaches where the banks are unprotected by bulkheads or revetments for comparison with available previously obtained aerial photographs. In places where these comparisons indicate that significant erosion has taken place, make cross-sections of the eroding banks, take samples from the exposed face (for analyses to determine specific weights) and compute volumes and tonnages eroded. Reduce to terms of tons per year.

d. Dredging. Re-examine all dredging methods with a view to determining: 1) Runback of solids from disposal areas; 2) Losses from scows; 3) Inflow of sediments with wash-water from sand and gravel dredges; 4) Determine whether the passage of the drags of hopper dredges notably increases the turbidity of the water in the wake of the dredge. (This phase of the investigation should be given a low priority in the order of tasks to be performed, as the District has concluded that presently available talent and funds should be used to first inquire into the basic characteristics of the estuary. However, FWPCS data suggest that this may be a major source.)

e. Inflow from Municipal Sewers. Determine, during times of storm runoff, the tonnages of solids contributed by a few of the larger sewers. Obtain drainage area data (total and for those sewers studied) from municipal authorities, adjust the observations to correspond to the total drainage areas, and reduce to terms of tons per year.

f. Marine Life. Obtain the services of a marine biologist familiar with the ecology of the Delaware for the purpose of evaluating the "sediment" production of the vegetal and animal life in the waters of the estuary.

g. Industrial Contributions. Determine the inflows of solids in terms of tons per year emanating from the outfalls, selecting only the larger sewers for study. (FWPCA data suggest that this is a major source.)

h. Oceanic Sources. In the light of other information (see Par. 57a), evaluate the possibility that sediments from the ocean move upstream 58 miles to the most downstream reach of channel that is subject to appreciable shoaling.

SHOALING

55. Assemble data on ALL shoaling in the estuary and the principal tributary streams, also privately or non-Federally maintained areas, and compute average annual shoaling rates in terms of cubic yards. Determine specific weights of these shoals, and reduce the volumes to tons per year.

SEDIMENT BUDGET

56. Prepare a sediment budget in detail and draw balances downstream of every significant shoaling reach.

HYDRAULIC INVESTIGATIONS

57. a. For Locating Null Points. Review available current velocity observations in the reach from Station +209 (Mile 65) to Cross Ledge Lighthouse (Mile 27) and determine whether additional data are necessary for ascertaining the locations of null points corresponding to low, median, and high rates of fresh water discharges.

b. For Study of Shoaling and Adjoining Non-Shoaling Areas. Undertake a program of observations of current velocities at Station +121 and at Station +165 with a view to determining why the former shoals so heavily while the latter experiences negligible shoaling. The observations should cover a wide range of conditions, including neap and spring tides occurring during low, normal, and high fresh water discharges. The observations should be made from as large a number of points in these cross sections as are feasible, if necessary to consist of the use of one fixed station and one or preferably two boats that successively occupy other stations. The observations should include data on the velocities as close to the bottom as possible, but just above the non-moving soft material at the bottom, and at several additional points in the vertical. The purpose of these observations is to determine what differences exist between the currents in the two locations, and for this reason it is essential that the observations at the two cross sections be made simultaneously.

SEDIMENT SAMPLING

58. Water samples should be taken at the points and at the times that current velocity observations as described above are made. These should be analyzed for sediment content in terms of parts per thousand by weight of sample, also the pH value; the temperature should be determined at the time of sampling. A sufficient number of the samples taken close to the bottom at one of the sampling stations in each cross section should be combined to provide enough suspended sediment to permit additional analyses. These should provide data on the kind of material in transport, including mineralogical determinations, grain size and specific gravity, and grain shape, including whether flocculation has taken place.

BOTTOM SAMPLING

59. Samples of the shoal in the cross section at Station +131 at several locations at the surface of the bottom and at increments of depth down to virgin material should be collected and analysed for mineralogical content, grain size and specific gravity, and grain shape, including whether flocculation has taken place. Samples retrieved will be analyzed to identify, insofar as possible, the original source of the shoal material. It is envisioned that the samples will be used to determine the organic and inorganics which are found in representative samples to determine their separate sources and to determine the relative columetric percentage that the organic and inorganic is contributing to the shoal.

OTHER OBSERVATIONS

60. In addition to the observations described above, it is considered desirable to undertake a program of observations similar to those to be made in the Savannah River in the near future with a view to determining the flocculating potential of the estuary's waters.

REFERENCES

(1) Boggs, Trans ASCE 1929

(2) Black, Trans ASCE 1929

(3) Table II-1, Delaware Basin Report, U.S.A.E. District, Philadelphia, 1960

(4) Appendix N, Page 12, ibid.

(5) Appendix M, Plate 20, ibid.

(6) Appendix M, Plate 5, ibid.

(7) Appendix M, Plate 8, ibid.

(8) Appendix M, Plate 29, ibid.

(9) U.S.A.E. District, Philadelphia, Drawing 22811, 1949.

(10) U.S.A.E. Committee on Tidal Hydraulics, Technical Bulletin No. 13, 1967.

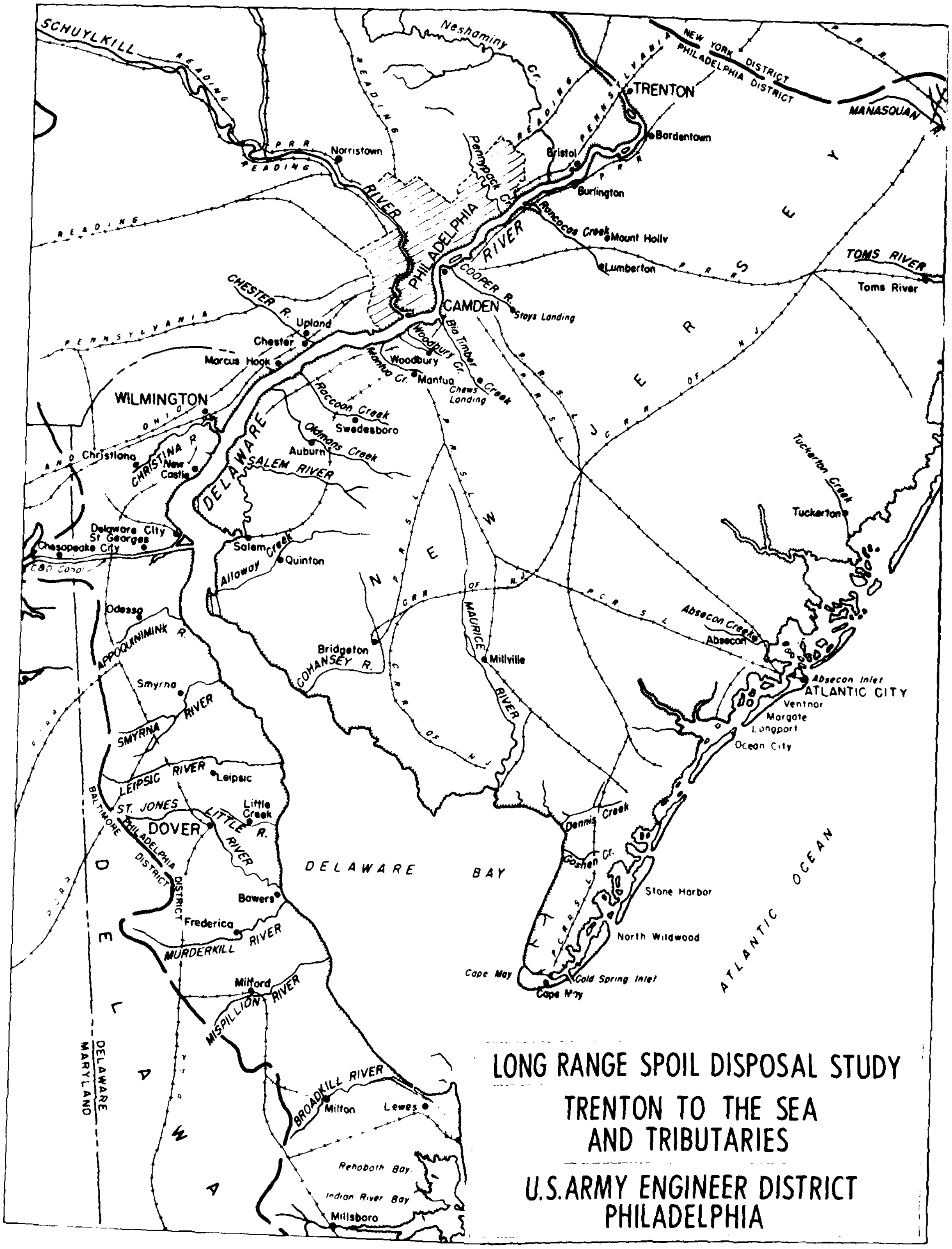
(11) University of California report: "Flume Studies of Transport of Sediment in Estuarial Shoaling Processes", 1962.

(12) U.S. Geological Survey report: "Sedimentation Processes in Estuaries", 1965.

(13) U.S.A.E. District, Philadelphia, drawings:

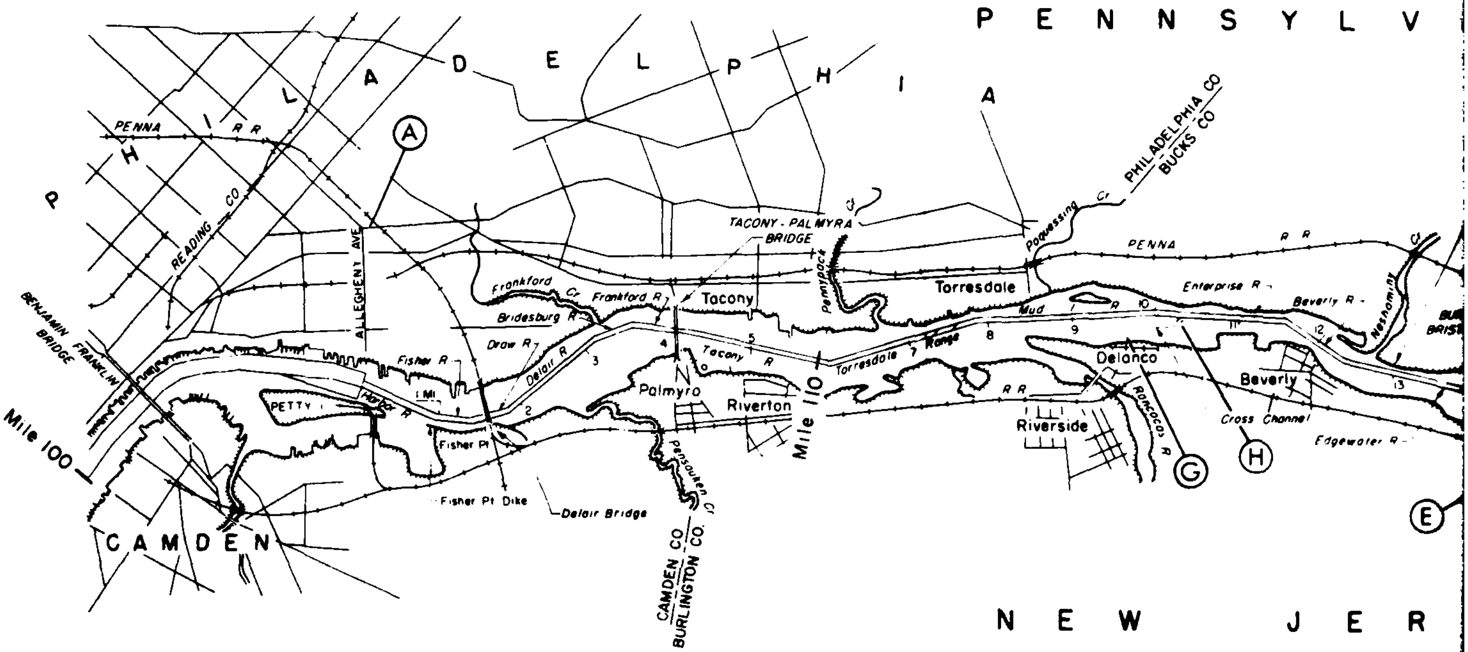
a. "Delaware River, Philadelphia to Trenton, Comparative Shoaling Rates", two sheets, 3 April 1967.

b. "Delaware River, Philadelphia to Sea, Comparative Shoaling Rates", two sheets, 3 February 1967.



LONG RANGE SPOIL DISPOSAL STUDY
TRENTON TO THE SEA AND TRIBUTARIES
U.S. ARMY ENGINEER DISTRICT PHILADELPHIA

PLATE 1

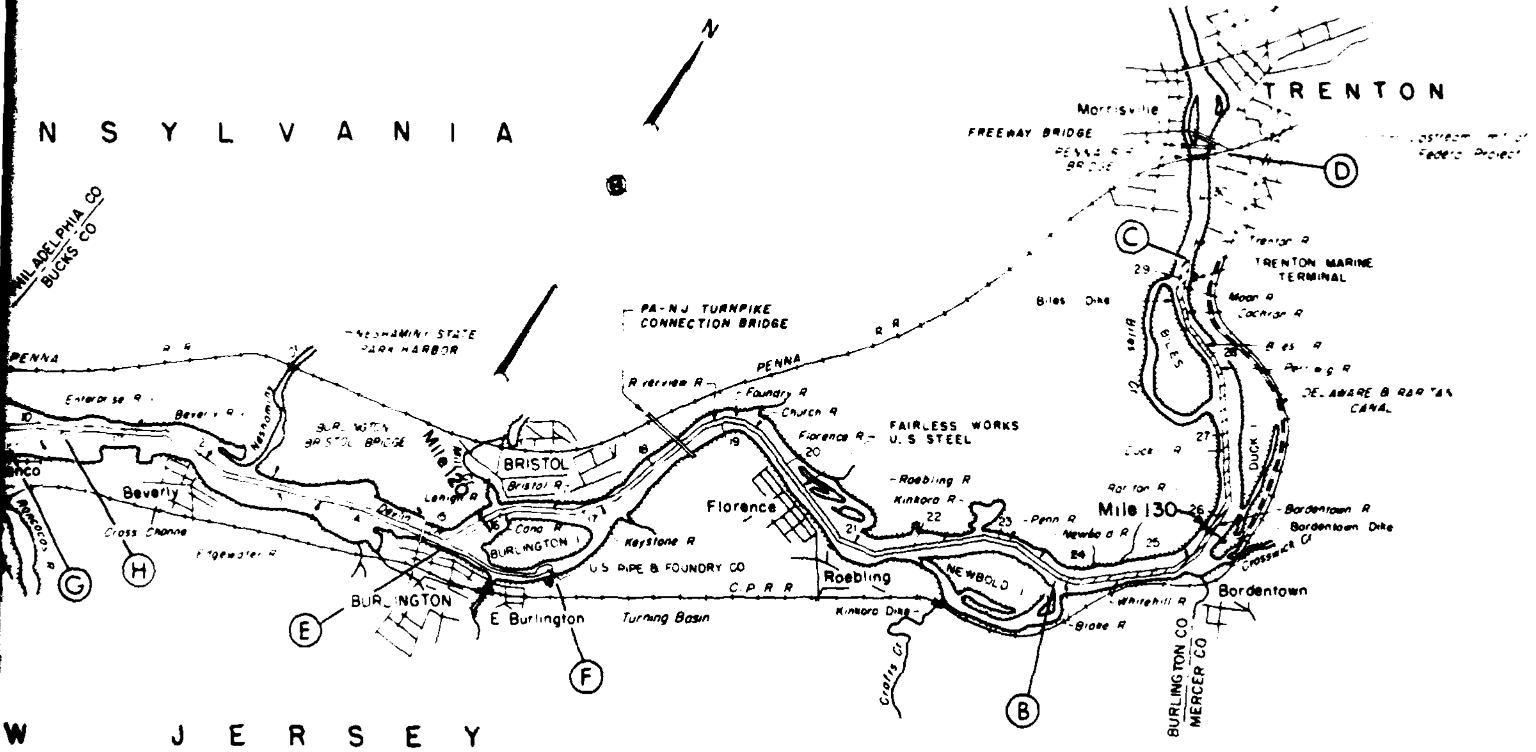


AREA WHERE NEW WORK REMAINS TO BE DONE

Scale in Miles

1 0 1 2 3

CHANNEL DIMENSI		
LOCATION	DEPTH	W
A – B	40 FT.	
B – C	35 FT	
C – D	12 FT	
E – F	20 FT.	
G – H	8 FT.	



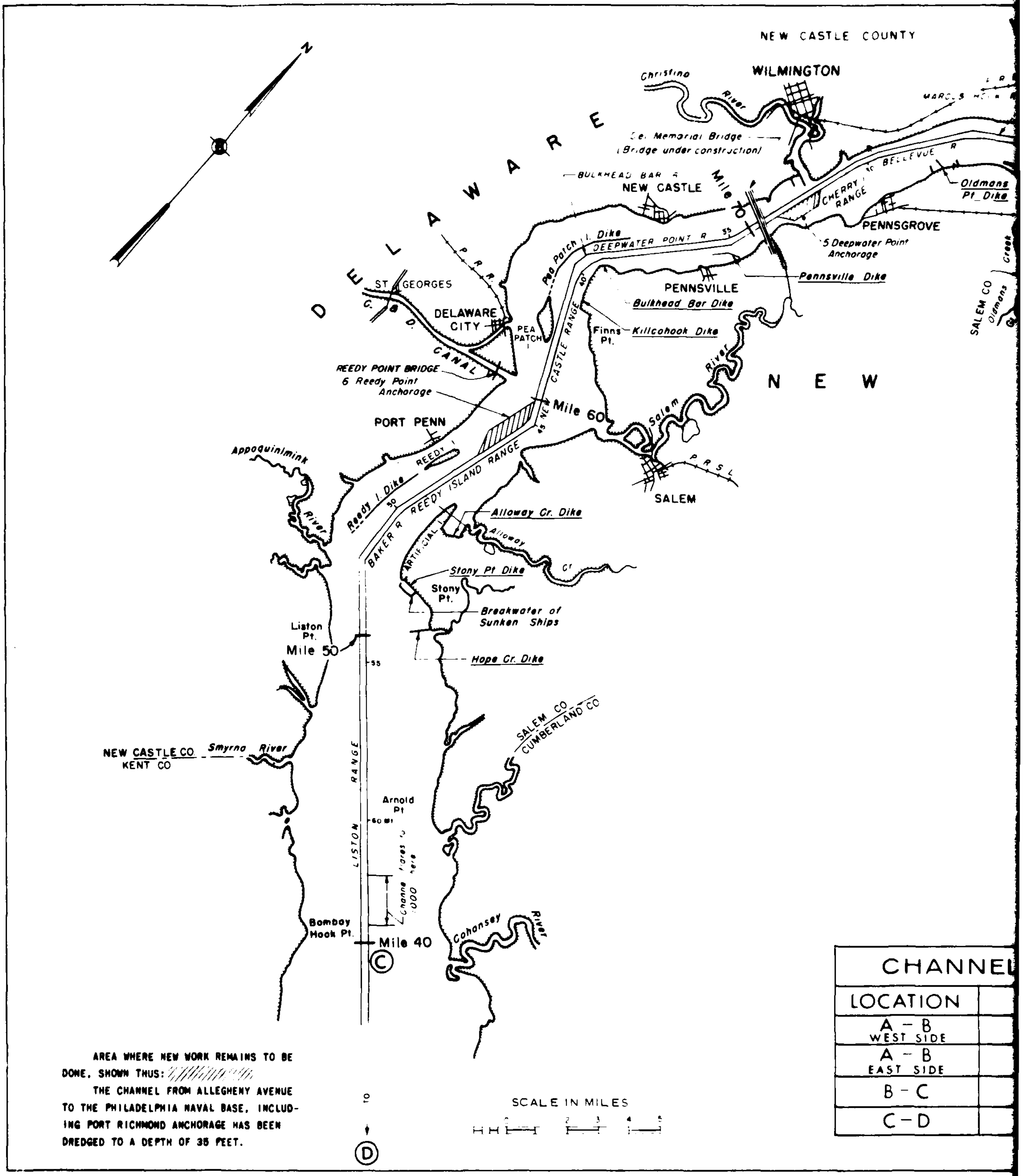
HANNEL DIMENSIONS		
ION	DEPTH	WIDTH
B	40 FT	400 FT
C	35 FT	300 FT
D	12 FT	200 FT
F	20 FT	200 FT
H	8 FT	200 FT

LONG RANGE SPOIL DISPOSAL STUDY

DELAWARE RIVER
PHILADELPHIA TO TRENTON

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA

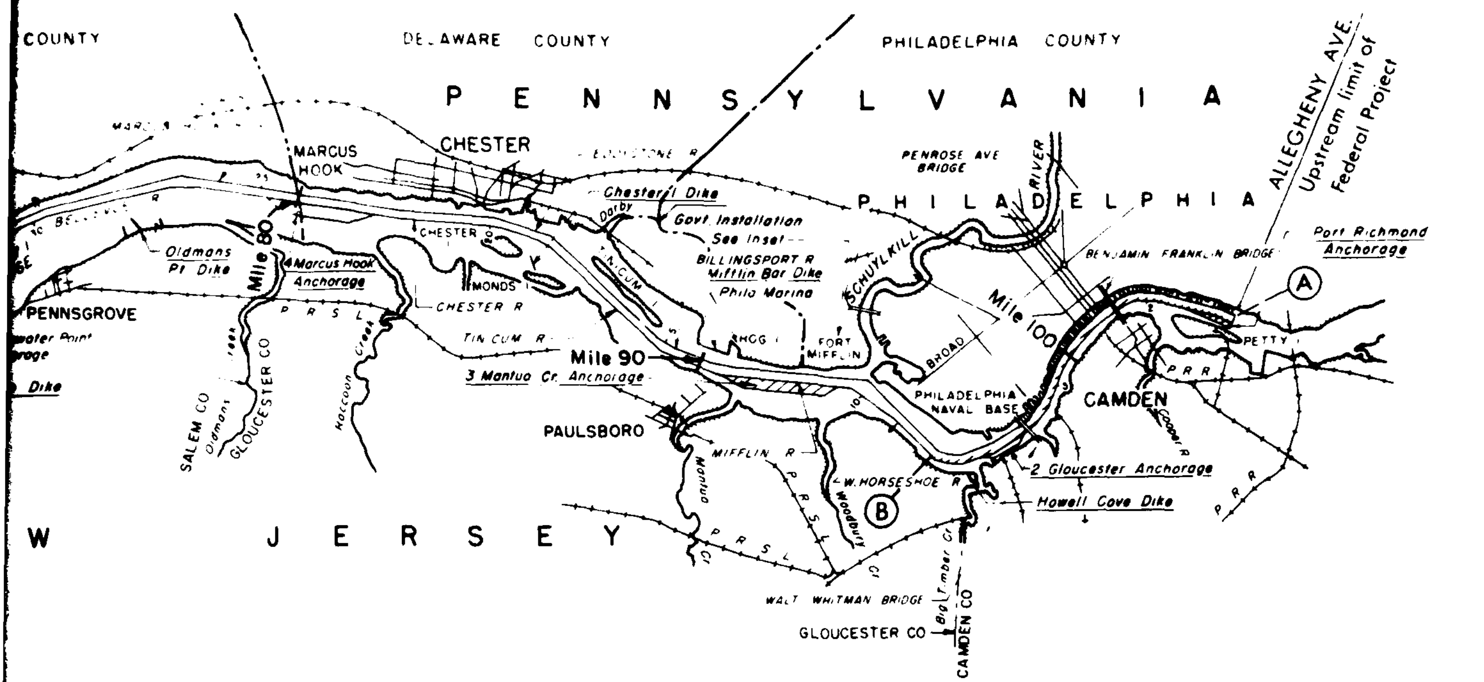
PLATE 2



AREA WHERE NEW WORK REMAINS TO BE DONE, SHOWN THUS:

THE CHANNEL FROM ALLEGHENY AVENUE TO THE PHILADELPHIA NAVAL BASE, INCLUDING PORT RICHMOND ANCHORAGE HAS BEEN DREDGED TO A DEPTH OF 35 FEET.

CHANNE
LOCATION
A – B WEST SIDE
A – B EAST SIDE
B – C
C – D



CHANNEL DIMENSIONS

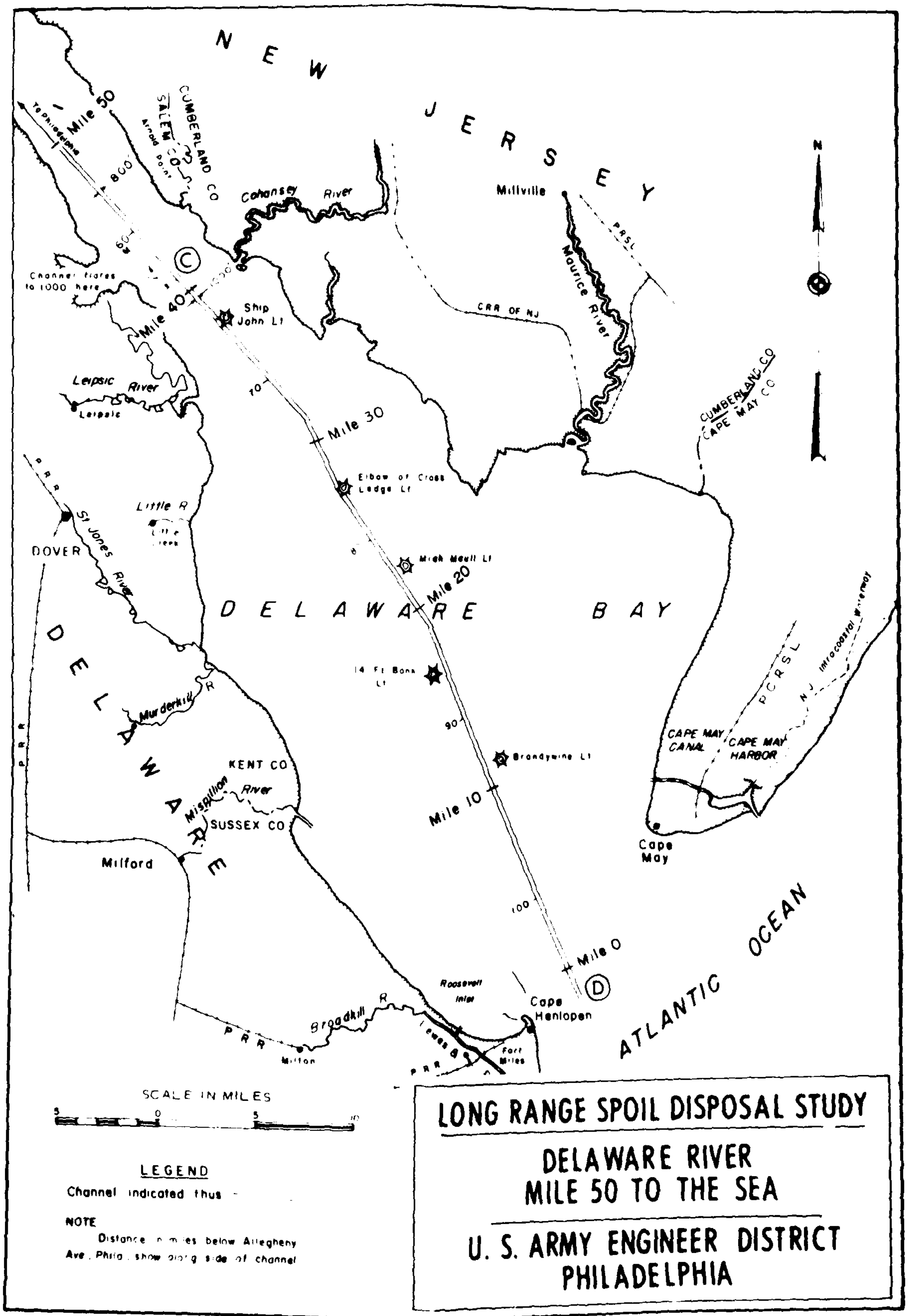
LOCATION	DEPTH	WIDTH
A – B WEST SIDE	40 FT	400 FT–500 FT
A – B EAST SIDE	37 FT	500 FT–600 FT
B – C	40 FT	800 FT
C – D	40 FT	1000 FT

LONG RANGE SPOIL DISPOSAL STUDY

DELAWARE RIVER PHILADELPHIA TO MILE 40

U. S. ARMY ENGINEER DISTRICT PHILADELPHIA

PLATE 3

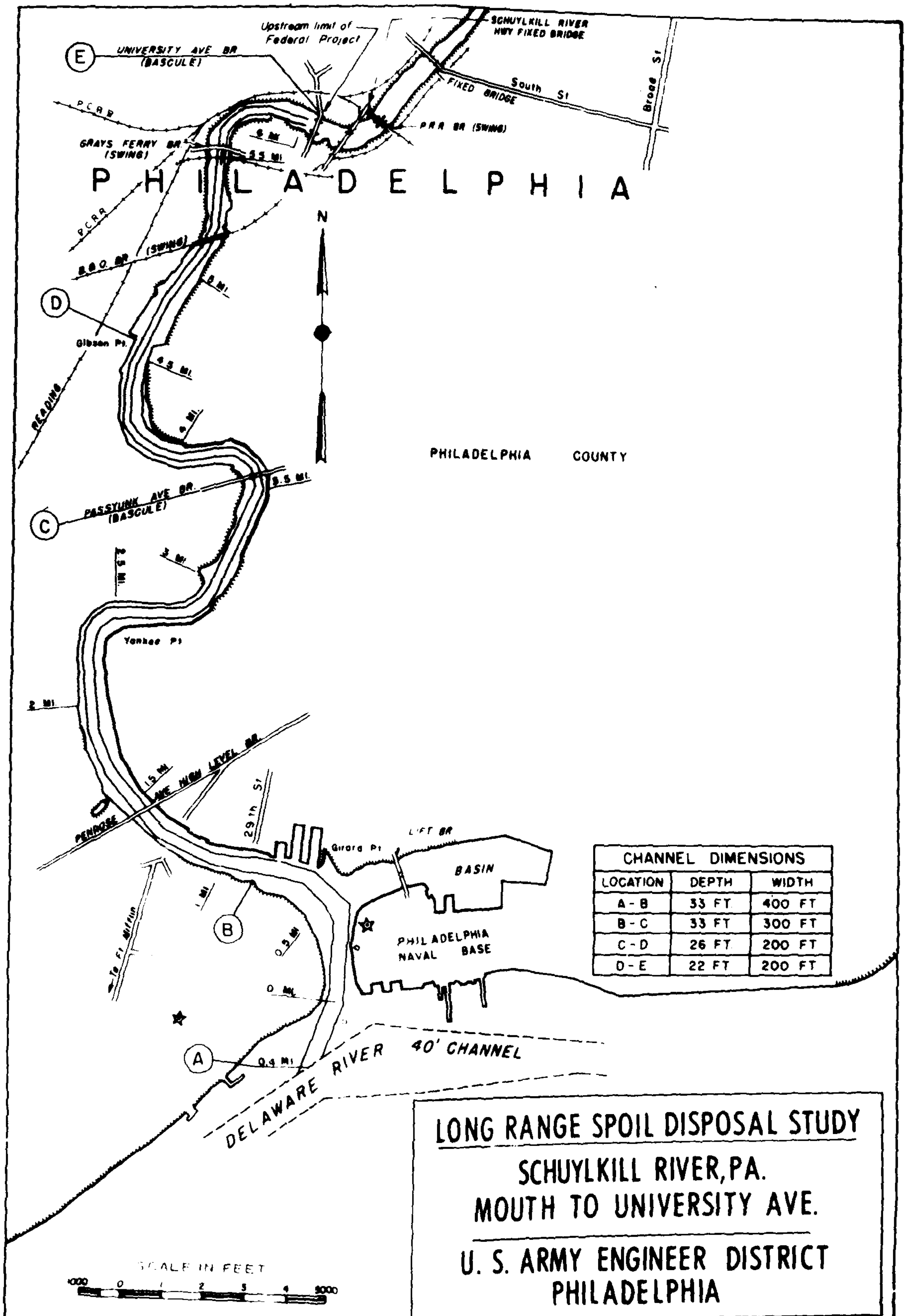


LONG RANGE SPOIL DISPOSAL STUDY

DELAWARE RIVER
MILE 50 TO THE SEA

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA

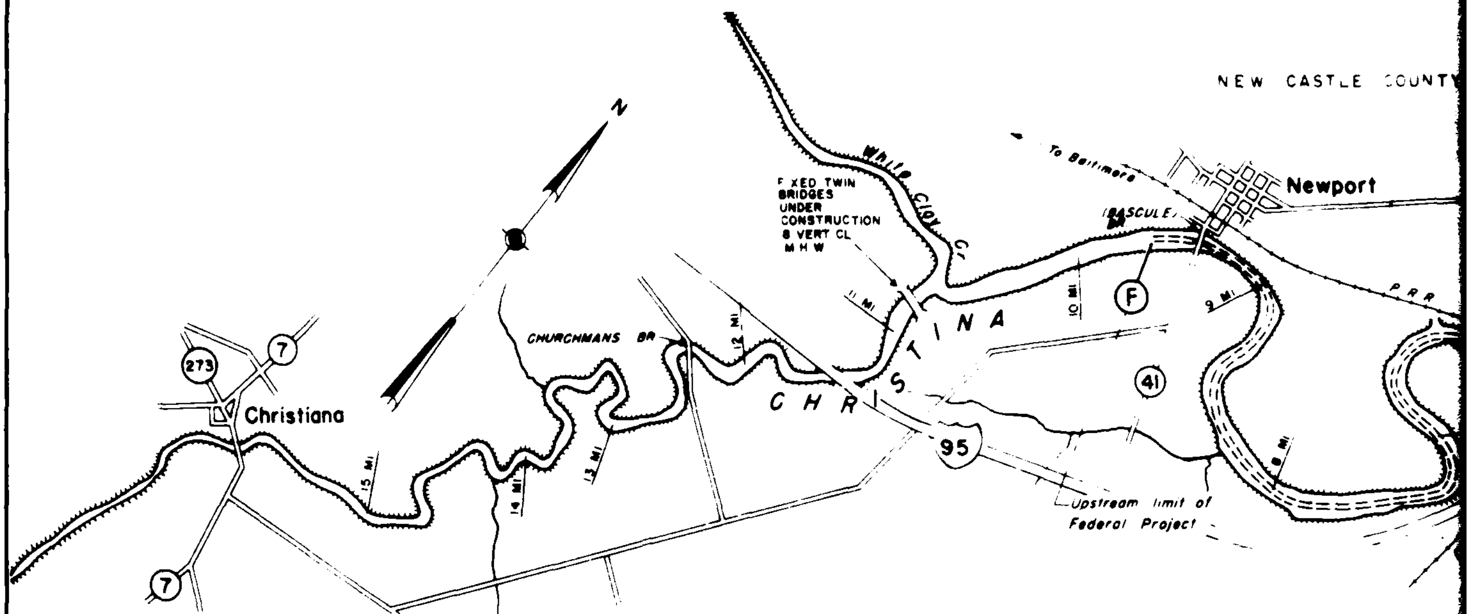
PLATE 4



CHANNEL DIMENSIONS

LOCATION	DEPTH	WIDTH
A - B	33 FT	400 FT
B - C	33 FT	300 FT
C - D	26 FT	200 FT
D - E	22 FT	200 FT

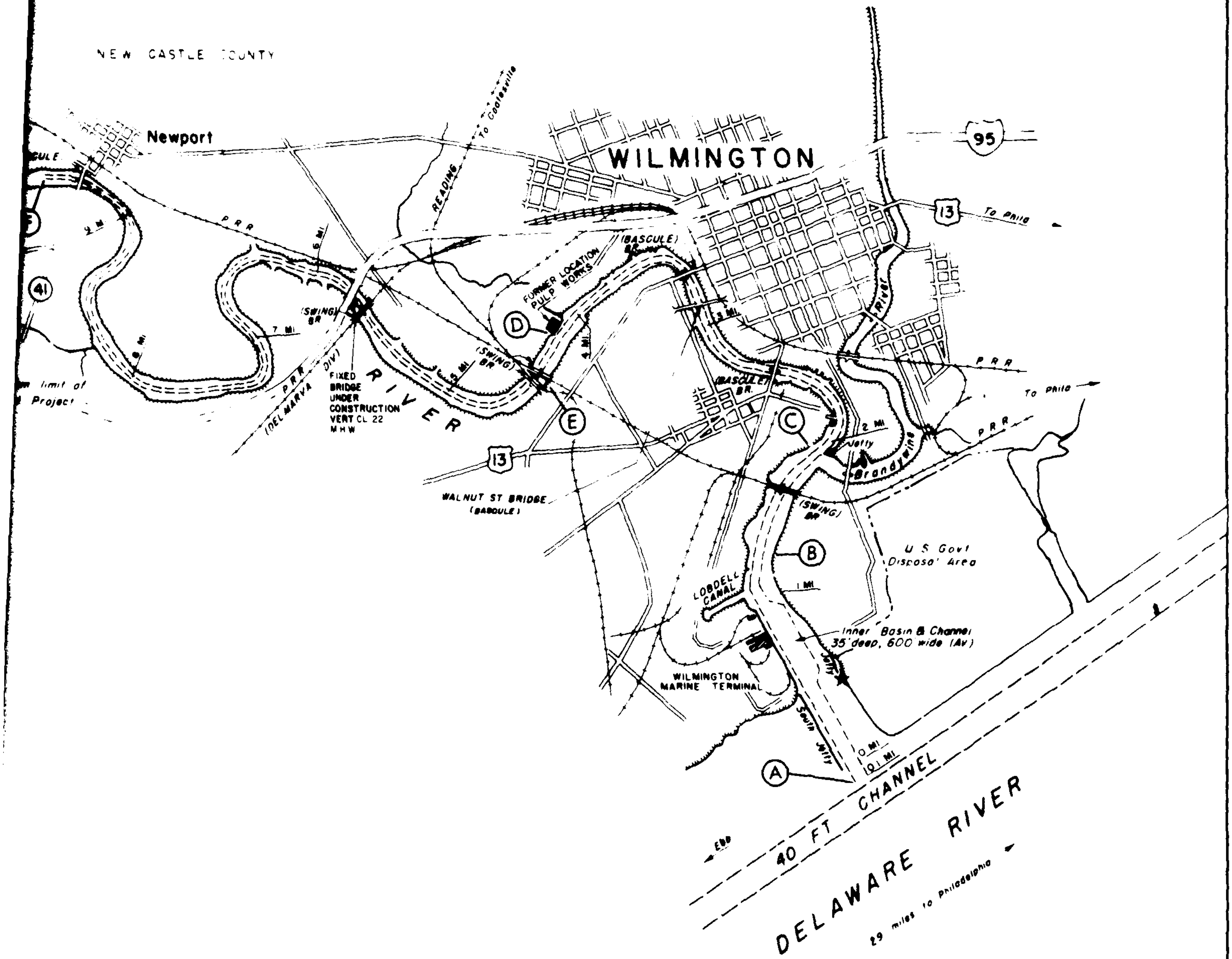
PLATE 5



SCALE IN FEET

1000 0 2 3 4 5 6 7000

CHANNEL DIMENSIO		
LOCATION	DEPTH	V
A – B	35 FT	4
B – C	21 FT	2
C – D	21 FT	2
D – E	10 FT	2
E – F	7 FT	1



...NNEL DIMENSIONS		
...ON	DEPTH	WIDTH
	35 FT	400 FT
	21 FT	25[illegible] FT
	21 FT	2[illegible]0 FT
	10 FT	2[illegible]0 FT
	7 FT	[illegible] FT

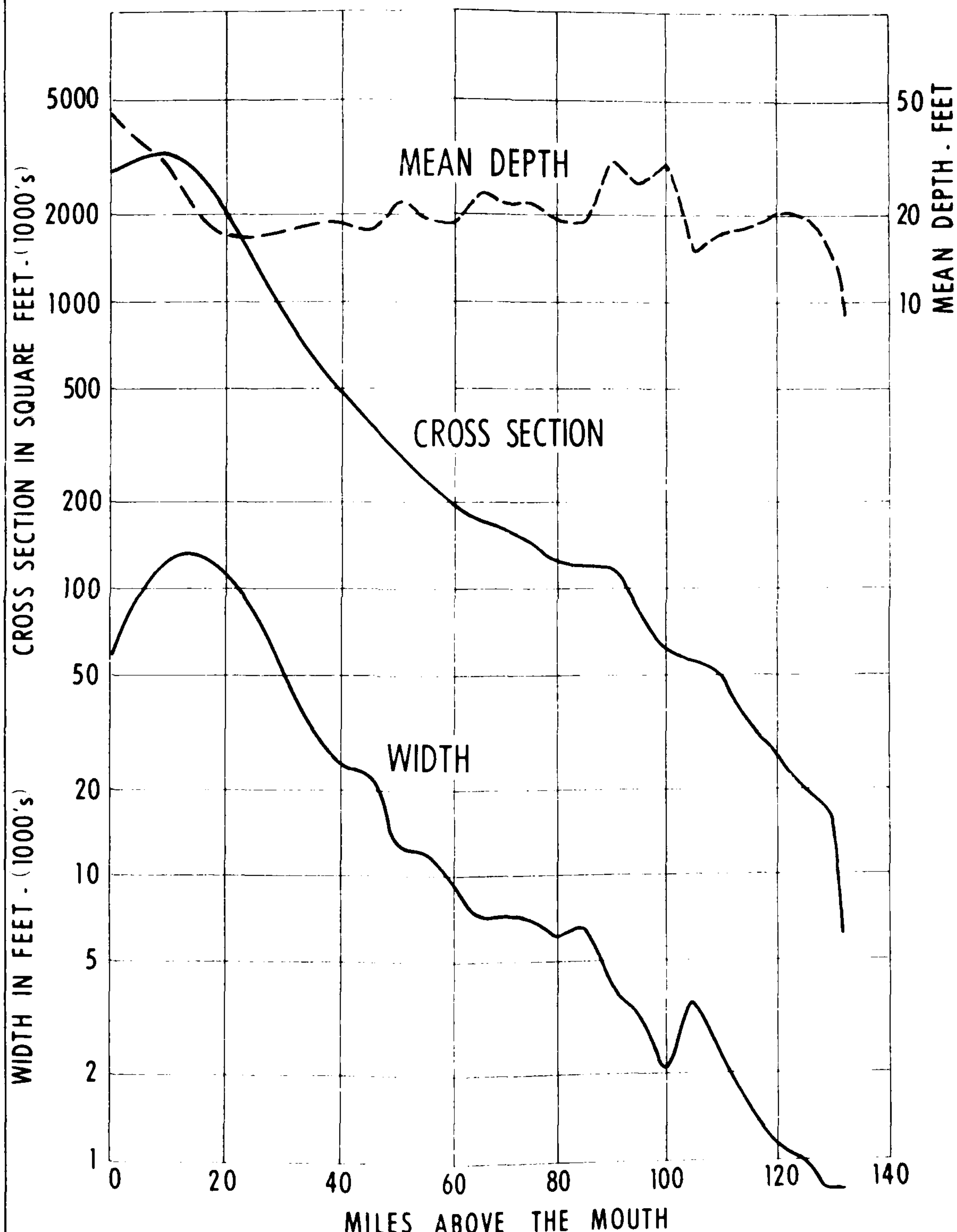
LONG RANGE SPOIL DISPOSAL STUDY

WILMINGTON HARBOR
CHRISTINA RIVER, DEL.

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA

PLATE 6

DELAWARE ESTUARY PHYSICAL CHARACTERISTICS



Semi-Logarithmic 4 Cycles x 10 to the inch